Appendix A

Delta Levees Seismic Risk Assessment Modeling 30 and 50 Breach Scenarios

RMA

RESOURCE MANAGEMENT ASSOCIATES, INC.

SUISUN CITY, CALIFORNIA

FINAL REPORT

DELTA LEVEES SEISMIC RISK ASSESSMENT MODELING 30 AND 50 BREACH SCENARIOS

March 2005

Table of Contents

Table of Figures

List of Tables

Executive Summary

Hydrodynamic and water quality modeling was performed to analyze the impacts of multiple levee failures during a seismic event in the Delta. Two different levee breach scenarios were simulated: a 50 breach scenario, including 20 breaches on Sherman Island, and a 30 breach scenario in which no breaches occur on Sherman Island. A Baseline simulation was also performed for comparison. Results from these simulations are used to estimate potential duration of export pumping disruption resulting from salinity intrusion into the Delta.

Model boundary conditions were developed to approximate a series of "normal" water years. Simulations were performed using predicted tide for June 2002 through February 2005 and historical river flows for June 2002 through September 2003. Starting October 1, 2003 the flows for October 2002 through September 2003 are repeated for the remainder of the simulations. The breach event occurs on July 1, 2002.

All exports are stopped following the event and remain off until salinity levels return to acceptable levels. Given the hydrology, operating strategy, and breach repair schedule used in the simulations, exports are not resumed until all breaches were repaired. Historical exports are used throughout the Baseline simulation.

Breaches are repaired based on the following priority: Byron and Bethel islands are repaired first for public safety. Islands along the San Joaquin River are repaired next, with the islands with the fewest breaches being repaired soonest. South Delta islands are given last priority for repair.

The 50 breach (with Sherman Island breaches) and 30 breach (without Sherman Island breaches) simulation results indicate the following key points.

- *For the hydrology, operating strategy, and breach closure schedule developed for this study, export pumping is disrupted for approximately 15 months for the 30 breach scenario, and 27 months for the 50 breach scenario due to elevated salinity levels in the Delta. These disruption periods, which are the entire time periods required for breach repair, are a function of the operating strategy and repair schedule. These simulations are a first attempt at modeling such extreme breach scenarios and it is likely that a refined operating strategy or repair schedule could reduce the pumping disruption.*

- *Export pumping cannot resume until all South Delta levee breaches are repaired. High salinity water is drawn into the South Delta Islands and if exports are resumed before the South Delta Island levee breaches have been repaired, tidal exchange with the islands will raise salinity of the exports beyond acceptable levels (acceptable levels are assumed here to be approximately 800 umhos/cm or about 500 mg/L of total dissolved solids).*

- *Breach closure scheduling is important. Salinity results for the 30 and 50 breach scenarios indicate that following the breach event, South Delta islands fill with high salinity water and do not flush out in the subsequent wet season. If South Delta Islands had been closed first, some export pumping may have been possible while the Central Delta Islands were still being repaired.*

- *Reduction of Sacramento and San Joaquin River flows after the breach event to conserve water in upstream reservoirs for later flushing is not beneficial. A "Low Flow" operation was explored in which immediately after the breach event, reservoir releases were cut and river flows reduced to minimum flows. Extra water was retained in reservoir storage for release later after levee repairs had begun but early enough to provide full flood control capacity during the wet season. Comparison of the "Low Flow" operation to model runs without reducing reservoir flows indicated that flushing flows immediately following the breach event appear to be more effective than storing the same amount of water and using it for flushing later in the year. The highest priority should be to minimize the salinity in the flooded islands in the South Delta which is best achieved by reducing salinity levels in the Central Delta as soon as possible.*

- *Comparing the 30 and 50 breach simulations, Sherman Island breaches appear to have little impact on intrusion of salinity into the Delta, aside from the length of time to final breach closure. Because of the high NDO resulting from exports being turned off without reducing reservoir releases, salinity levels around Sherman Island are at times lower than Baseline salinities. With more normal salinity gradients in the Western Delta, breaches on Sherman Island may have a greater impact on Delta salinity.*

1 Introduction

1.1 Background

The State of California and the Federal Government, through the CALFED Bay-Delta Program, are working together to stabilize, protect, restore, and enhance the Sacramento-San Joaquin Delta Estuary system because of its importance to California's natural environment and economy.

The Delta levee system is vulnerable to failure during earthquakes. The consequences that a western Delta levee failure could have on the State Water Project (SWP) and Central Valley Project (CVP) export facilities are of prime concern. Several years ago, a seismic risk assessment determined that a significant seismic risk is present and that the consequences to Delta resources could be severe.

The Delta Levees Seismic Risk Assessment modeling will provided example salinity consequences for two levee breach scenarios using the RMA Bay-Delta model to explicitly simulate the dynamic breach, repair, and recovery process. This study is an extension of previous work as part of the Delta Levees Risk Assessment Team (LRAT) supported by CALFED. In earlier LRAT studies, single levee breaches on Sherman Island, Brannon and Andrus Islands and Bacon Island were analyzed as well as ten simultaneous breaches on Sherman Island, Brannon and Andrus Islands, Bacon Island, Twitchell Island, Bradford Island, Jersey Island, Bethel Tract, Holland Tract, Palm Tract and Orwood Tract. These simulations were performed for the period of July 1992 through January 1993.

1.2 Study Objective

The objective of the hydrodynamic and water quality modeling for this study is to estimate potential duration of water pumping disruption resulting from salinity intrusion into the Delta following a multiple levee failure event.

Separate simulations with and without breaches on Sherman Island are used to assess the economic viability of undertaking major retrofit activities on Sherman Island to reduce or eliminate the contribution of Sherman Island to the seismic risk.

This report presents hydrodynamic and water quality modeling results for two different levee breach scenarios: a 50 breach scenario, including 20 breaches on Sherman Island, and a 30 breach scenario in which no breaches occur on Sherman Island.

2 Model Development

2.1 Model Configuration

The numerical models used for the 50 breach and 30 breach seismic risk assessment scenarios are constructed using the RMA finite element modeling system for surface waters. The existing RMA model of San Francisco Bay and Sacramento – San Joaquin Delta is modified to include the islands to be breached and flooded.

A historical simulation is performed using the existing RMA model of the system to produce a baseline case for comparison with the breach case results.

2.1.1 Bay-Delta Model

In support of previous and current studies of Bay-Delta hydrodynamics and water quality, RMA has developed a detailed and calibrated finite element model of the Sacramento-San Joaquin Delta and San Francisco Bay system. The model encompasses San Francisco Bay to the Golden Gate, and all the significant rivers and channels of the Delta system (Figure 2-1). In performing a model simulation, tidal stage is imposed at the Golden Gate boundary location (Figure 2-1). Simulations also include all of the Delta rim flows, Delta Island consumptive use, exports flows, South Delta barrier operations, operation of the Delta Cross Channel and the Suisun Marsh Salinity Control gate, and other minor structures found in the Delta. Data for model boundary conditions and for model calibration are primarily acquired from the San Francisco Bay-Delta Interagency Ecological Program (IEP) database at www.iep.ca.gov and the California Data Exchange Center (CDEC) at cdec.water.ca.gov .

The RMA Bay-Delta model employs two dimensional depth-averaged elements to represent the large open water areas of the system, such as San Francisco Bay and Franks Tract, as well as the major channels and confluences of the Sacramento and San Joaquin Rivers. Other channels of the Delta are represented by one-dimensional channel elements.

The existing RMA Bay-Delta model is modified to include Delta islands to be breached and flooded. A full description of the modifications made to the network for this study is provided in the following section.

2.1.2 Seismic Risk Assessment Model

The existing RMA model of San Francisco Bay and Sacramento – San Joaquin Delta is modified to include the following islands to be breached and flooded.

- Sherman Island (50 breach only)
- Brannan/Andrus Island
- Twitchell Island
- Bouldin Island
- Bradford Island
- Webb Tract
- Venice Island
- Jersey Island
- Bethel Tract
- Mandeville Island
- Quimby Island

- Holland Tract
- Bacon Island
- McDonald Tract
- Palm Tract
- Orwood Tract
- Woodward Island
- Lower and Upper Jones Tract
- Byron Tract
- Victoria Island

Breaches of varying number and size connect each island to existing adjacent channels. All islands and breaches are represented as two-dimensional depth-averaged.

Accurate topographic data were not available early in the model development process. Initial island elevations were set using USGS 7.5 minute series topographic maps. Once the Delta IFSAR digital elevation data were made available (provided by Joel Dudas of DWR), model elevations were spot checked for accuracy and adjusted as necessary.

Breach widths range from 500' to 1600' and all breach depths are set at approximately -30' MSL. Breach sizes are summarized in Table 2-1.

The areas of the finite element mesh modified for the seismic risk assessment simulations are shown in Figures 2-2 and 2-3 for the 30 breach and 50 breach cases, respectively.

Table 2-1 Breach sizes.

Breach Location	Breach Size (feet)
Sherman Island #1	1300
Sherman Island #2	1300
Sherman Island #3	1000
Sherman Island #4	1000
Sherman Island #5	1000
Sherman Island #6	700
Sherman Island #7	700
Sherman Island #8	1000
Sherman Island #9	1000
Sherman Island #10	1000
Sherman Island #11	1000
Sherman Island #12	700
Sherman Island #13	1300
Sherman Island #14	1300
Sherman Island #15	700
Sherman Island #16	700
Sherman Island #17	700
Sherman Island #18	700
Sherman Island #19	1000
Sherman Island #20	1000
Jersey Island #1	1000
Jersey Island #2	1000
Jersey Island #3	1000
Jersey Island #4	700
Bradford Island	1300
Twitchell Island	1600
Brannon/Andrus Island #1	1300
Brannon/Andrus Island #2	1300
Webb Tract	1000
Bethel Tract #1	500
Bethel Tract #2	500
Holland Tract #1	1300
Holland Tract #2	700
Palm Tract #1	1300
Palm Tract #2	700
Orwood Tract #1	1000
Orwood Tract #2	700
Bouldin Island	1300
Venice Island	1600
Mandeville Island	1300
Quimby Island	1300
Bacon Island #1	1300
Bacon Island #2	1300
Woodward Island #1	1000
Woodward Island #2	1000
McDonald Tract	1300
Lower Jones Tract	1300
Upper Jones Tract	1300
Bryon Tract	500
Victoria Island	1000

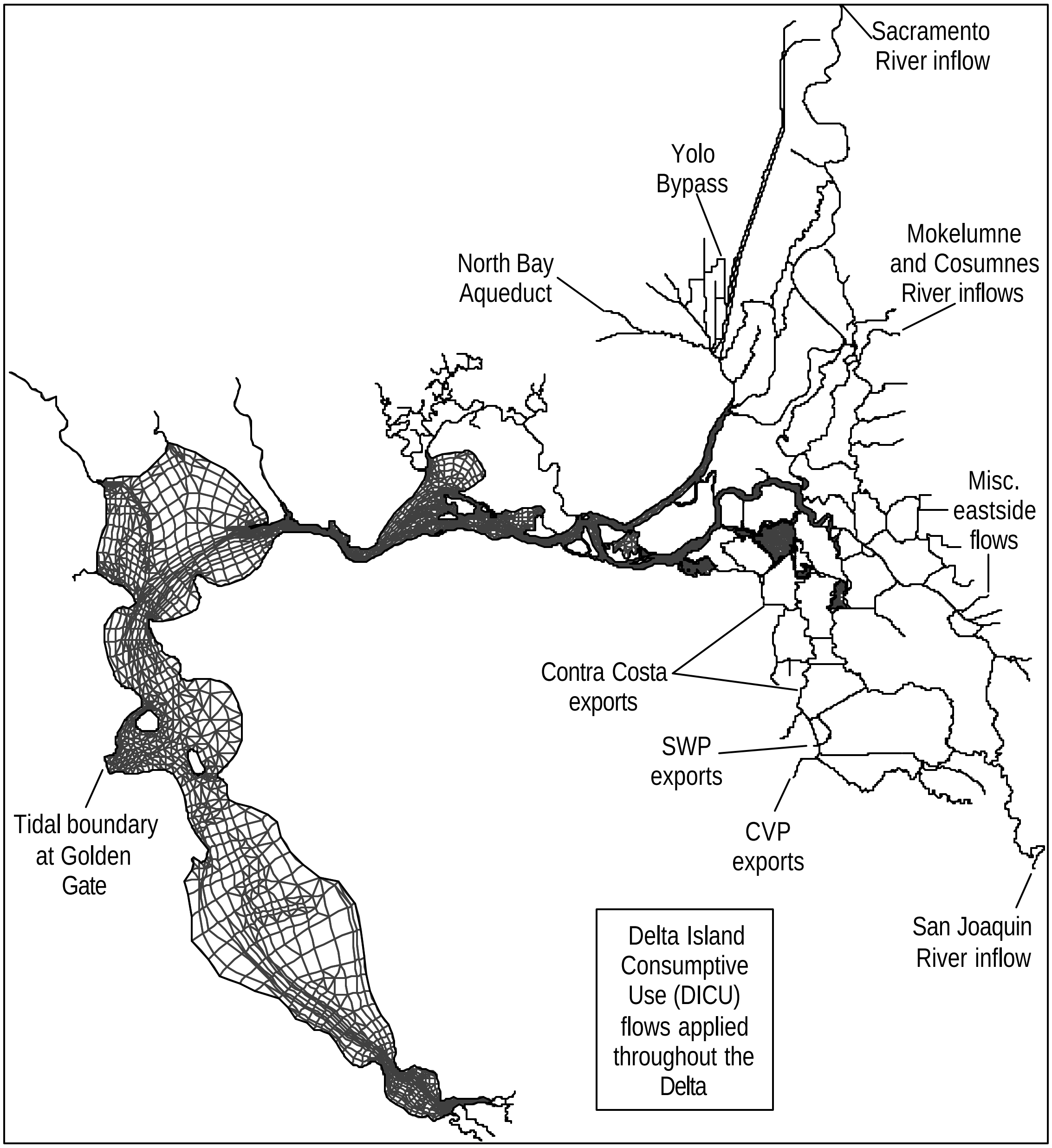

Figure 2-1 Model Configuration for Bay-Delta model.

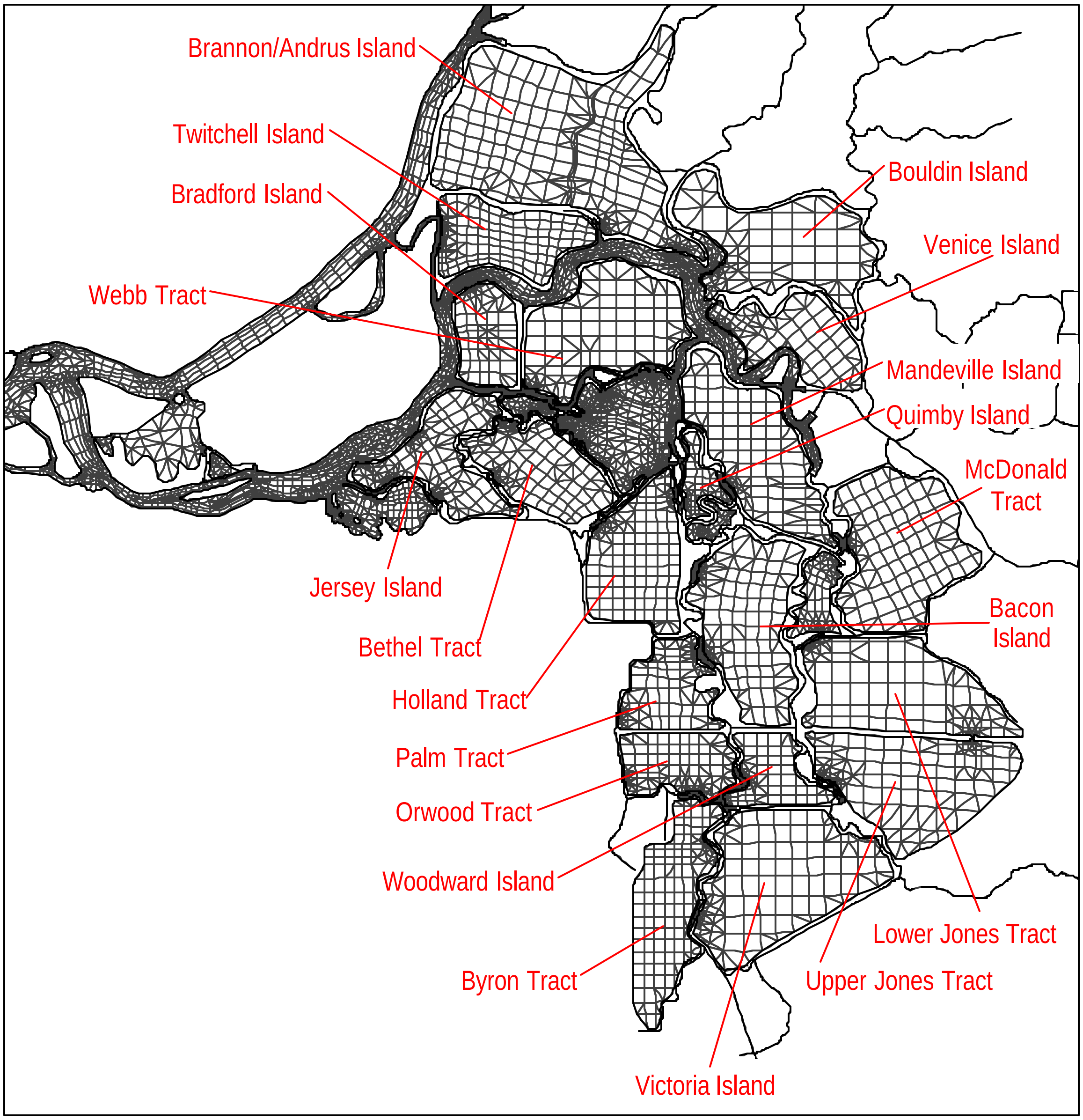

Figure 2-2 Detail of finite element mesh modifications for 30 breach simulation (no Sherman Island breaches).

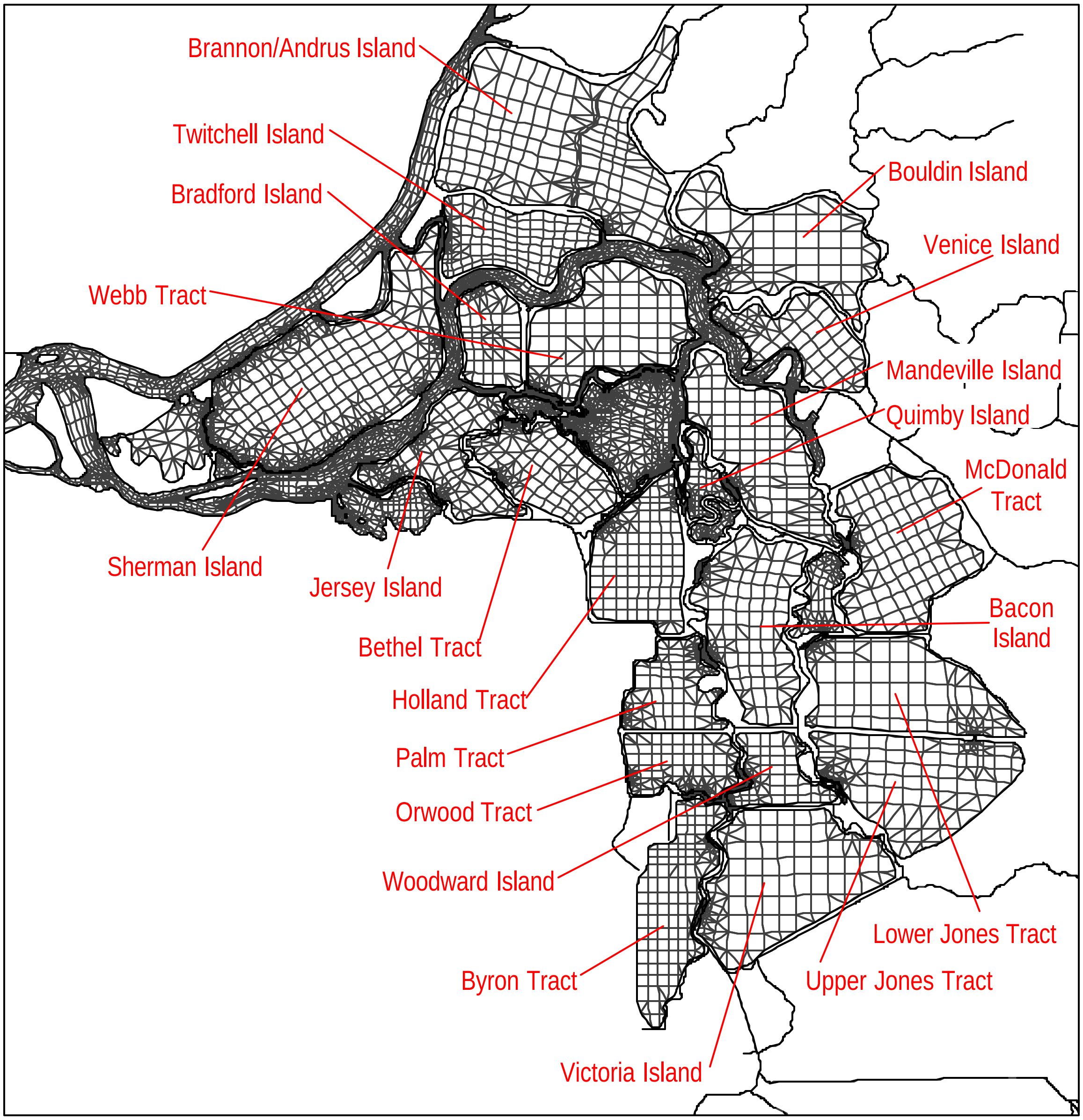

Figure 2-3 Detail of finite element mesh modifications for 50 breach simulations (with Sherman Island breached).

3 Levee Breach Analysis

3.1 Introduction

Two levee breach analysis simulations are performed: a 50 breach analysis including twenty breaches on Sherman Island, and a 30 breach analysis with no breaches on Sherman Island. The results of these simulations are compared with a Baseline simulation.

Simulations begin on June 1, 2002. The levee breach event occurs on July 1, 2002. All levees are breached simultaneously.

3.2 Baseline Simulation

The Baseline simulation represents existing conditions with no levee breaches. The simulation begins June 1, 2002 and runs for 2years and 9 months.

3.2.1 Boundary Conditions

Boundary conditions locations are shown in Figure 2-1.

A non-repeating 15-minute predicted tide for June 1, 2002 through February 28, 2005 is applied at the Golden Gate.

Historical flows and associated EC, Delta Islands Consumptive Use (DICU), and gate and barrier operations are used for June 1, 2002 through September 30, 2003. Starting October 1, 2003 flows and gate operations for October 1, 2002 through September 30, 2003 are repeated. This period represents a normal water year. Sacramento and San Joaquin River flows, and the combined exports (CVP, SWP, Contra Costa and North Bay Aqueduct) for this period are plotted in Figure 3-1.

Observed flow data are used to set boundary conditions for the Sacramento River, San Joaquin River, Cosumnes River, Mokelumne River and all exports including CVP, SWP, Contra Costa exports at Old River and Rock Slough, and the North Bay Aqueduct. Yolo Bypass and miscellaneous eastside flows are defined using Dayflow values. DICU data are provided by DWR.

Golden Gate EC is set at a constant value of 50,000 umhos/cm. Observed EC data are used to set boundary conditions for the Sacramento River and San Joaquin River. Yolo Bypass EC is set to Sacramento River values. All remaining inflows are set at constant estimated values.

3.3 Levee Breach Simulations

The simulation period for the 30 breach simulation is from June 1, 2002 through February 28, 2004. The 50 breach simulation period is longer due to longer levee repair time. It runs from June 1, 2002 through February 28, 2005. The levee breach event occurs on July 1, 2002.

3.3.1 Boundary Conditions

The same Golden Gate tide described for the Baseline simulation is used for both of the levee breach simulations.

For both breach scenarios, Baseline historical exports and DICU flows are used during June 2002. Starting July 1 (the time of the breach event) all exports and DICU flows are turned off and remain off for each breach simulation until the last levee breach is closed. Final closure occurs on October 8, 2003 for the 30 breach and October 16, 2004 for the 50 breach case. Because DICU flows include evaporation and precipitation, during the time when DICU is turned off, a monthly varying parameter is applied to account for evaporation and/or precipitation based on meteorological data from the California Irrigation Management Information System (CIMIS).

Table 3-1 summarizes export pumping disruption for the breach simulations.

With the exports turned off, the Net Delta Outflow (NDO) is significantly higher for the breach cases than for the Baseline case. The historical NDO used for the Baseline case and the NDO with exports off, used for the breach cases, are plotted in Figure 3-2.

River flows are the same as for the Baseline simulation with the exception of minor adjustments to the Sacramento River flows. The Net Delta Outflow (NDO) during March through May is kept above 20,000 cfs while levee breaches are still open. This requires only a few days of increased flows in the Sacramento River during 2003 for the 30 breach case and during 2003 and 2004 for the 50 breach case.

Gate and barrier operations are modified for the breach scenarios. During the time that breaches are open, the Delta Cross Channel is only closed during times of high flow and the South Delta barriers are not installed.

EC boundary conditions remain the same as for the Baseline simulation.

Table 3-1 Export disruption summary for breach simulations.

Simulation	Exports turned off	Exports resumed
30 Breach	7/1/02	10/8/03
50 Breach	7/1/02	10/16/04

3.3.2 Breach Repair and Island Pump-out

Breaches are repaired based on the following priority. Bethel Island and Byron Tract are repaired first for public safety. Islands adjacent to the San Joaquin River are repaired next, with priority given to islands with fewer breaches. South Delta islands are given last priority. This strategy was developed based on earlier studies during which simulations were performed with fewer breaches. These simulation results indicated that the Central Delta had the greatest impact on salinity at the export facilities.

Pump-out of each island begins immediately after all breaches for the island are repaired. It is assumed that the available pumping capacity is 5,000 cfs with a maximum of 1,000 cfs utilized for each island, except for Sherman Island where the full 5,000 cfs is available. Due to the closure schedule, the full available pumping capacity is only utilized for Sherman Island and all other islands are pumped out at the 1,000 cfs rate.

Pump-out in the model is represented as a 1,000 cfs (or 5,000 cfs for Sherman Island) source in a neighboring channel. The EC applied to this source is based on the computed EC in the island.

Tables 3-2 and 3-3 show breach repair and island pump-out schedules for the 30 breach and 50 breach simulations.

3.3.3 Low Flow Simulations

An initial hypothesis was made that following the breach event, it would be beneficial to reduce river flows to minimum flows so that water could be stored in the reservoirs into the fall and winter in case the upcoming winter was dry and did not provide sufficient flows to flush some of the high salinity water from the Delta. At the time of the breach event, there were 2 million ac-ft of upstream storage available for water conservation storage even after consideration of flood control pool requirements.

For the low flow simulations, the 30 and 50 breach scenarios were simulated with Sacramento River flows reduced to 3,000 cfs and San Joaquin River flows reduced to 400 cfs following the breach. The river flows returned to historical values from October 2 through October 15, 2002. Between October 15 and December 17, 2002 all of the stored water was released in addition to the historical flows. All other boundary conditions and operations were kept the same as for the simulations discussed in section 3.3.1 above.

The results of these simulations showed that the immediate increase in EC in the Delta and breached islands that results from the reduced river flows cannot be flushed during the high flow period even with the addition of the stored flows, and EC levels remain higher in the Delta than with historical river flows.

These low flow simulations were therefore abandoned. The results for the short span of simulation are included on the plots in Figures 3-28 through 3-39.

A tradeoff for storing the water during the summer and early fall is the risk that if the extra water is stored into the winter, releases may be required during the high flow period to maintain flood control pools. Extra water released at such times would not increase the flushing effectiveness of the already high flows. This, in fact, would have been the case with the hydrology simulated, if an attempt was made to store the extra water any longer.

More importantly, the water stored is not available for immediate flushing following the breach event. The low flow simulations indicated that flushing flows during the months immediately following the breach event are more effective than the same amount of water saved up and used for later flushing, particularly during the fall for a pre-flush before high winter flows occur. Based on this finding, it may be useful to investigate the effect of increasing the NDO for the first 30 to 45 days following the breach event and then decreasing the NDO to make up for the extra releases.

Table 3-2 Breach repair and island pump-out schedule for 30 breach case.

Island	Start breach repair	End breach repair/Begin pump-out	Pump-out complete
Byron Tract	7/12/02	8/4/02	9/5/02
Bethel Tract	8/4/02	8/29/02	9/10/02
Bradford Island	8/10/02	9/11/02	9/22/02
Twitchell Island	8/27/02	10/24/02	11/17/02
Webb Tract	8/29/02	10/13/02	11/24/02
Jersey Island	9/11/02	12/8/02	12/25/02
Brannon/Andrus Island	11/27/02	1/11/03	4/11/03
Bouldin Island	12/8/02	1/22/03	3/10/03
Venice Island	1/11/03	3/10/03	4/7/03
Mandeville Island	1/11/03	2/25/03	3/5/03
Holland Tract	1/22/03	4/9/03	5/1/03
Quimby Island	2/25/03	4/11/03	4/15/03
Victoria Island	4/9/03	5/24/03	6/30/03
Lower and Upper Jones Tract	3/10/03	6/8/03	8/14/03
McDonald Tract	4/24/03	6/8/03	7/30/03
Palm Tract	5/24/03	7/23/03	8/6/03
Orwood Tract	6/8/03	8/9/03	8/20/03
Bacon Island	7/10/03	9/19/03	10/29/03
Woodward Island	8/9/03	10/8/03	10/19/03

Table 3-3 Breach repair and island pump-out schedule for 50 breach case.

Island	Start breach repair	End breach repair/Begin pump-out	Pump-out complete
Byron Tract	7/12/02	8/4/02	9/5/02
Bethel Tract	8/4/02	9/19/02	10/1/02
Bradford Island	8/10/02	10/27/02	11/7/02
Twitchell Island	8/27/02	11/9/02	12/3/02
Webb Tract	8/29/02	11/3/02	12/15/02
Jersey Island	9/11/02	1/12/03	1/29/03
Brannon/Andrus Island	11/27/02	2/20/03	5/21/03
Bouldin Island	12/8/02	3/11/03	4/27/03
Venice Island	1/11/03	4/26/03	5/24/03
Sherman Island	2/20/03	1/20/04	2/2/04
Mandeville Island	1/11/03	1/21/04	3/5/04
Holland Tract	1/22/03	3/18/04	4/9/04
Quimby Island	2/25/03	3/19/04	3/23/04
Victoria Island	4/9/03	5/2/04	6/8/04
Lower and Upper Jones Tract	3/10/03	5/16/04	7/22/04
McDonald Tract	4/24/03	6/16/04	8/7/04
Palm Tract	5/24/03	7/13/04	7/27/04
Orwood Tract	6/8/03	7/31/04	8/11/04
Bacon Island	7/10/03	9/9/04	10/19/04
Woodward Island	8/9/03	10/16/04	10/27/04

3.3.4 Simulation Results

Time series of stage for the Baseline, 30 breach and 50 breach scenarios are shown for June 15 through August 15, 2002 in Figures 3-4 through 3-7 at Old River (ROLD034), Frank's Tract, Antioch, and Sacramento River at Three Mile Slough. Time series locations are shown in Figure 3-3.

Stage time series for the two breach cases are nearly identical. Twenty-four hours after the breach event, the stage in Old River drops to approximately -3 m MSL, while the low tide for the Baseline simulation is at approximately -0.5 m MSL. The stage in Frank's Tract drops to nearly -2 m MSL six hours after the event. At Antioch and Three Mile Slough, the stage drops to around -1.5 m MSL an hour and a half after the event.

At ROLD034 and Frank's Tract, the tidal range is significantly dampened from Baseline conditions due to the increased volume in the Delta. At ROLD034, the maximum Baseline tidal range is approximately 1.2 m and the maximum breach case tidal range is approximately 0.2 m. At Frank's Tract, the maximum Baseline tidal range is approximately 1.2 m and the maximum breach case tidal range is approximately 0.5 m. The severe dampening of the South Delta tidal range results in diminished mixing of fresher water into the South Delta and thus trapping of the high salinity water in the South Delta.

Stage for the breach cases recovers to Baseline conditions after the breaches are closed.

In Figures 3-8 through 3-16, color contours of EC for the 30 breach simulation are shown just before the breach, 12 hours after the breach, at 1½, 2½, and 11 days, and one month following the breach and on January 1 and July 1 of 2003 and January 1, 2004. Plots for the 50 breach scenario are shown in Figures 3-17 through 3-27 at corresponding times, plus July 1, 2004, and January 1, 2005. Note that in the first three contour plots for each simulation, the beige areas within the islands indicate areas that are not inundated.

Tidally averaged EC time series for the locations shown in Figure 3-3 are plotted in Figures 3-28 through 3-38. Baseline, 30 breach, 30 breach low flow, 50 breach, and 50 breach low flow results are shown in each plot. At each of the first seven locations, a full scale plot is shown (note varying scales amongst locations), and a plot from zero to 1,000 umhos/cm is shown for better viewing of EC levels critical for pumping. The time period for the plots is June 15, 2002 through February 28, 2005. EC time series within some of the breached South Delta islands, plotted in Figures 3-35 through 3-38, are included as representative of high salinity water that is trapped in the South Delta islands. These plots cover the period from June 15, 2002 through December 31, 2003.

The general trend at each channel location is that EC rises sharply above Baseline conditions immediately following the breach, taking between three days and a month to reach the peak. In some of the breached islands of the South Delta, peak EC takes two months or more to be reached. EC in Old River at ROLD034 peaks at approximately 13,000 umhos/cm. At Frank’s Tract, EC peaks at around 30,000 umhos/cm, indicating that water from San Pablo Bay was pulled into the Central Delta. EC values greater than 12,000 umhos/cm are reached in some of the South Delta islands.

At most locations, EC levels decline somewhat quickly until sometime between July and September, 2002 and then level off or continue a gradual decline.

Between about May 2003 and the end of the year, EC levels at the SWP and CVP export locations appear to be acceptable for pumping. However, EC is still too high at ROLD034, and EC levels in the open islands are still near 2,000 umhos/cm. If pumping began under these conditions, the high EC water would be quickly drawn to the pumps. Regardless of EC levels elsewhere, pumping cannot begin until the breaches are closed.

In the South Delta, after final breach closure and resumption of export pumping in October, EC concentrations for both breach scenarios fall below Baseline levels and return to Baseline levels at the beginning of February of the following year. At Antioch, Three Mile Slough, and Frank’s Tract, both breach results drop below Baseline during September 2003 through the end of December 2003 because of higher NDO (due to lack of export pumping). The 30 breach case returns to Baseline levels at the beginning of February 2004 after final breach closure and resumption of export pumping. In 2004, the

50 breach case again falls below baseline levels during September through the end of December and then returns to Baseline levels at the beginning of February 2005 after final breach closure and resumption of export pumping. EC is still too high elsewhere for pumping to begin during the September through December period while breaches are still open.

To illustrate the dynamic fluctuations that result from pumping and barrier operations, EC results at the CVP intake are plotted in Figure 3-39 at half-hour intervals from November 1, 2002 through June 30, 2003. Note that the Baseline result shows daily fluctuations that are not present in the breach results. These fluctuations are caused by export pumping. During November through April the Baseline result shows a large increase in the maximum daily EC levels that is not seen in the breach results. This change is caused by the removal and installation of the South Delta barriers.

3.4 30 Breach vs. 50 Breach

At the South Delta locations (Rock Slough, Old River and the export pumps), the 50 breach simulation has a lower peak EC following the breach event than the 30 breach simulation. This is because with Sherman Island open, more fresh Sacramento River water is drawn into the South Delta following the breach event. After the peak occurs, EC time series in the South Delta are similar for the two breach scenarios until around May 2003. Around this time, the 30 breach EC generally begins to drop below 50 breach EC in the South Delta because Sherman Island breaches are being closed between April 2003 and January 2004 for the 50 breach case, while South Delta islands are being closed for the 30 breach case.

At Frank's Tract, EC for the two breach cases is quite similar. The initial peak EC following the breach event is slightly higher for the 30 breach case than for the 50 breach case, but the 50 breach EC does not fall quite as quickly as the 30 breach case and remains slightly higher until about the beginning of October 2002. The breaches are closing sooner for the 30 breach case and pump-out of the island begins sooner, which may cause the rate of decline in Frank's Tract EC to lessen and thus bring the 30 breach EC again above that for the 50 breach. The timing of breach closures and island pump-outs cause the EC for the two results to fall above and below one another at different times throughout the simulation.

At Antioch, the 50 breach EC is slightly higher for the first 6 months following the breach. At Three Mile Slough, the 50 breach EC is slightly lower for the first 6 months. After that, the timing of breach closures and island pump-outs cause the EC for the 30 and 50 breach cases to fall above and below one another at different times throughout the simulation.

At all locations, both simulations return to Baseline EC levels within 4 months of the final breach closure and resumption of export pumping. This occurs at the beginning of February 2004 for the 30 breach case, and at the beginning of February 2005 for the 50 breach case.

Results indicate that the breaching of Sherman Island has only a minor influence on salinity intrusion into the Delta. It may in fact even improve conditions slightly by allowing more fresh Sacramento River water to move southward into the Delta. This may not be the case, however, if the salinity gradient were more like normal conditions in the western Delta. With the exports turned off, the NDO is higher and thus the salinity near Sherman Island is at times lower than the Baseline salinity.

The important difference between the 30 and 50 breach scenarios is the breach closure schedule. Because the South Delta islands are closed a year sooner for the 30 breach case than for the 50 breach case, export pumps are able to be turned on a full year sooner. It is possible that a different breach closure schedule which calls for closure of the South Delta islands first may produce more similar final results between the two scenarios, and may allow pumps to be turned on sooner for both scenarios. The longer delay in beginning breach closures due to end capping of the 50 breaches would likely still cause a slightly slower recovery of EC levels in comparison with the 30 breach case.

3.5 Conclusions

Hydrodynamic and water quality modeling was performed to estimate potential duration of export pumping disruption resulting from salinity intrusion into the Delta following a multiple levee failure event.

Separate simulations with and without breaches on Sherman Island are used to assess the importance of undertaking major retrofit activities on Sherman Island to reduce or eliminate the contribution of Sherman Island to the seismic risk.

The 50 breach (with Sherman Island breaches) and 30 breach (without Sherman Island breaches) simulation results indicate the following key points.

- **For the hydrology, operating strategy, and breach repair schedule developed for this study, model results indicate that export pumping is disrupted for approximately 15 months for the 30 breach scenario, and 27 months for the 50 breach scenario due to elevated salinity levels in the Delta**. These disruption periods are the entire time required for breach repair. The operation strategy and breach repair schedule were developed based on the experience of members of the Levee Risk Assessment Team, and results of previous breach modeling. Because this is a first attempt at modeling such extreme breach scenarios, it is likely that refinements of the operating strategy and repair schedule could reduce the period of export disruption.

- **Export pumping cannot resume until all South Delta levee breaches are repaired**. When so many islands are breached simultaneously, very high salinity water is pulled all the way from San Pablo Bay into the Central Delta. Consequently all islands fill with water that is significantly above the salinity threshold for export.

Although salinity at the export facilities at times drops to levels that appear to be acceptable for pumping, if exports are resumed before the South Delta island levee breaches have been repaired, tidal exchange with the high salinity water in the islands will raise the salinity of export water beyond acceptable levels.

- **Breach closure scheduling is important**. The repair schedules used in the modeled scenarios were developed based on previous experience indicating that flooded islands in the Western and Central Delta were more likely to increase mixing of salt into the Delta and degrade the ability to move fresh water south from the Northern Delta. However, the simulations show that the South Delta islands are more important because they fill with high salinity water and do not flush out in the subsequent wet season. Although salinity levels in many of the islands next to the San Joaquin River rise higher following the breach event than those in the South Delta, the salinity washes out much more quickly. This is a result of flushing the Central Delta by stopping exports without decreasing reservoir releases and thus increasing Net Delta Outflow (NDO). Also, islands adjacent to the San Joaquin River recover more quickly during the wet season. Closing the South Delta islands first may eliminate the most problematic breaches first and allow export pumping to resume even before the other islands are closed, although simulations are not performed to confirm this. In the simulations that were performed, for both the 30 and 50 breach case the salinity in Franks Tract and the Central Delta is lower than the Baseline case during summer and fall of 2003. Had the South Delta islands been repaired some level of pumping should have been possible during that period by balancing exports and NDO.

- **Reduction of Sacramento and San Joaquin River flows after the breach event to conserve water in upstream reservoirs for later flushing is not beneficial.** A "Low Flow" operation was explored in which immediately after the breach event, reservoir releases were cut and river flows reduced to minimum flows. Extra water was retained in reservoir storage for release later after levee repairs had begun but early enough to provide full flood control storage during the wet season. This operation was based on the idea that flushing flows would be more effective once some of the levees had been repaired. However, comparison of the "Low Flow" operation with model runs using historical river flows indicated that conserving water in the reservoirs was not beneficial. With reduced NDO immediately after the breach event, tidal flows cause more high salinity water to mix from the Central Delta into the South Delta and to intrude into the breached South Delta islands. The islands do not flush out, even with augmented flows during the fall. Thus the higher salinity water remains in the islands and mixes with Old River and Middle River water, keeping concentrations in those channels elevated as well. In addition, the impact would be greater later on when the breaches are closed and the water being pumped from the islands is of higher salinity. The highest priority should be to minimize the salinity in the flooded islands in the South Delta which is best achieved by reducing salinity levels in the Central Delta as soon as possible following the breach event.

- **Comparison of the 30 and 50 breach salinity results indicates that Sherman Island breaches appear to have little impact on intrusion of salinity into the Delta, aside from the increasing the length of time to final breach closure.** Because of the high NDO resulting from exports being turned off without reducing reservoir releases, the salinity gradient is pushed seaward and salinity levels around Sherman Island are at times lower than Baseline salinities. Without a strong salinity gradient in the vicinity of Sherman Island, filling and draining of the island does not induce significant tidal mixing of salt toward the Delta. Also, since there are no exports, there is less exchange from the Sacramento toward the San Joaquin through Sherman Island than there would be if export pumping was drawing water south. With more normal summer salinity gradients in the western Delta and some level of export pumping, breaches on Sherman Island may have a greater impact on Delta salinity.

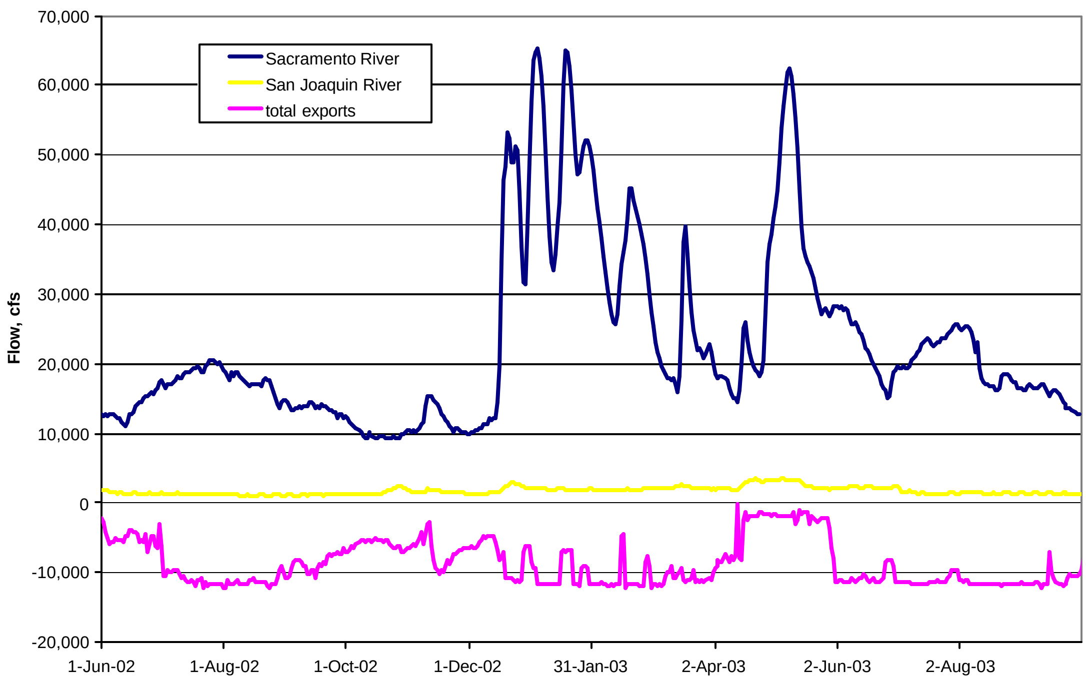

Figure 3-1 Historical Sacramento and San Joaquin River flows and total exports for June 1, 2002 through September 30, 2003.

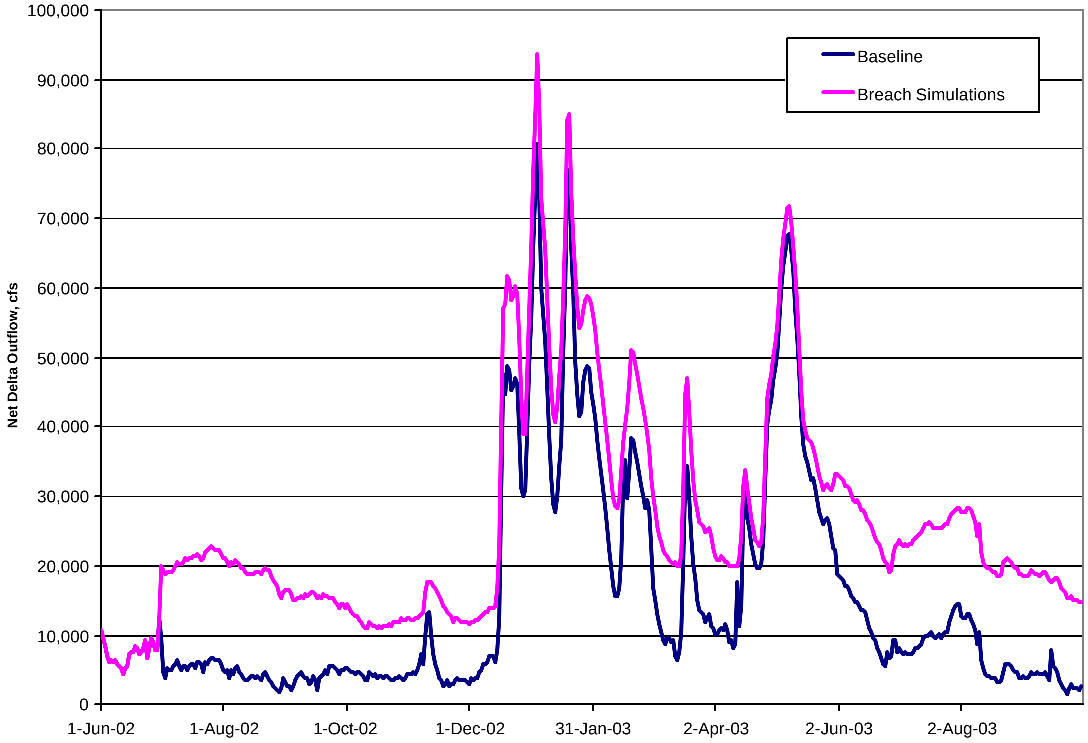

Figure 3-2 Net Delta outflow for Baseline and Breach simulations for June 1, 2002 through September 30, 2003.

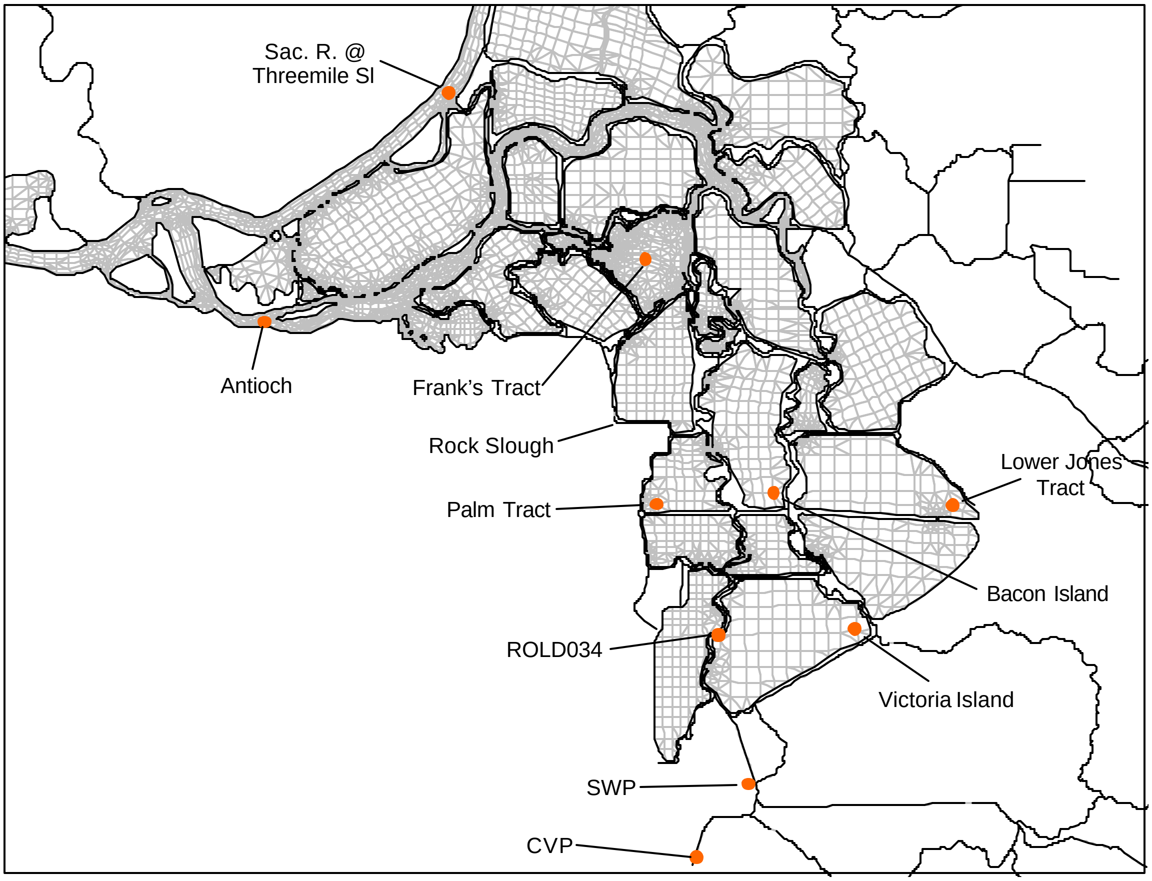

Figure 3-3 Stage and EC time series locations.

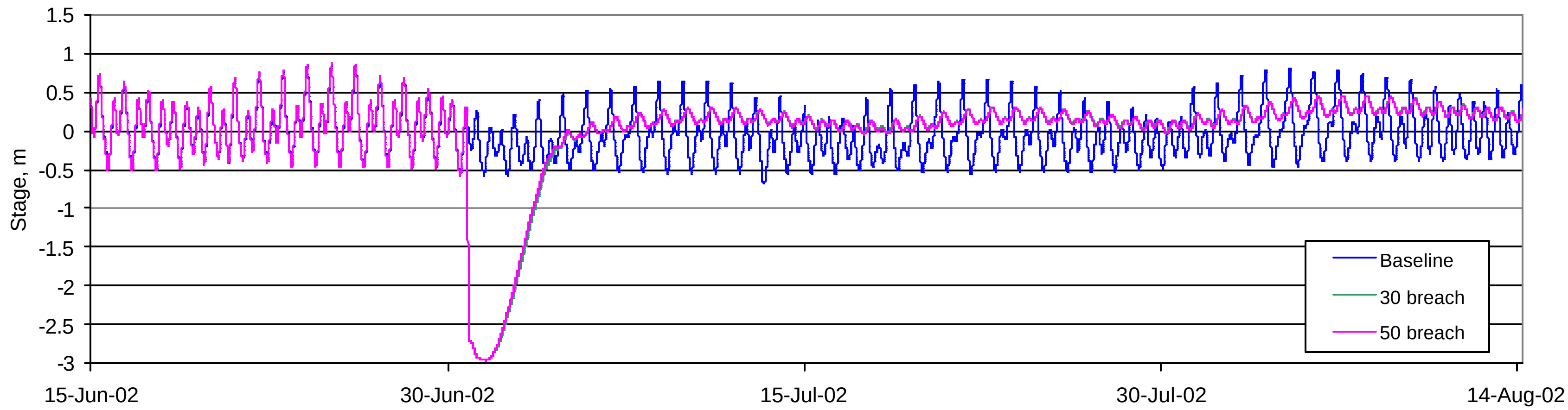

Figure 3-4 Stage time series at the Contra Costa water intake at ROLD034.

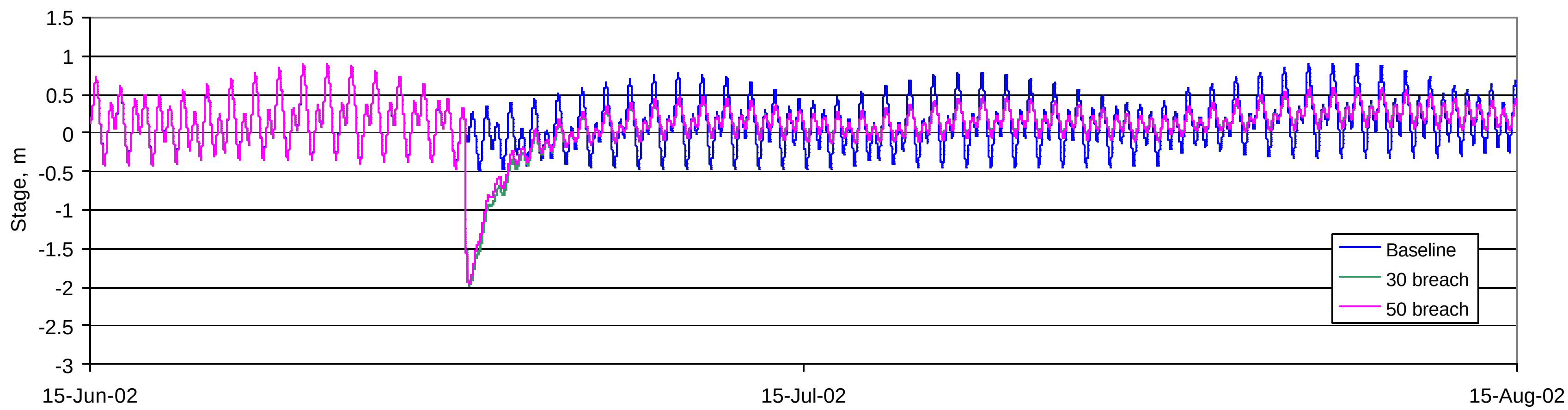

Figure 3-5 Stage time series at Frank's Tract.

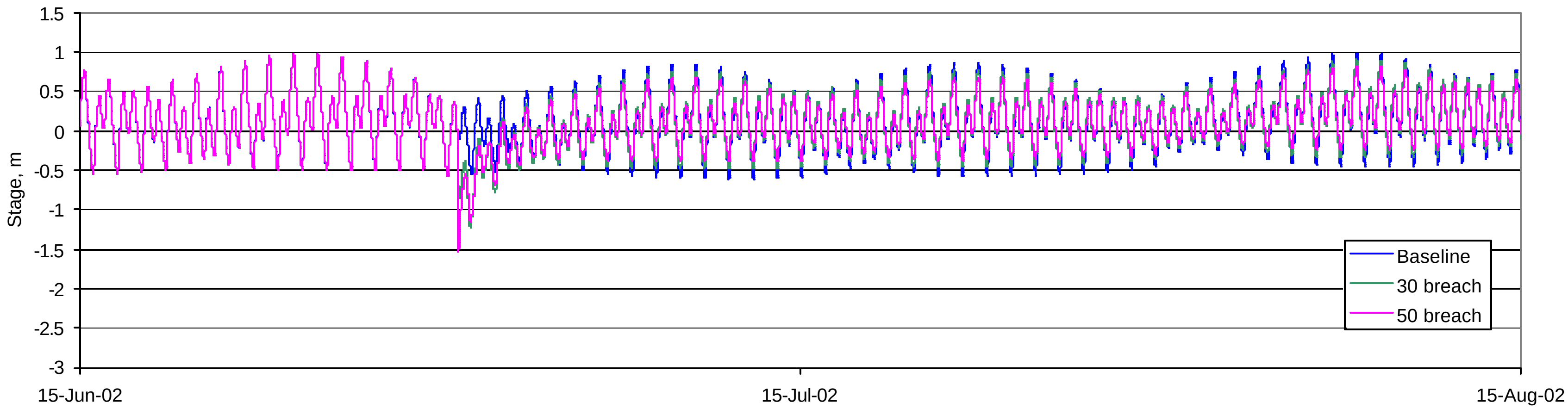

Figure 3-6 Stage time series at Antioch.

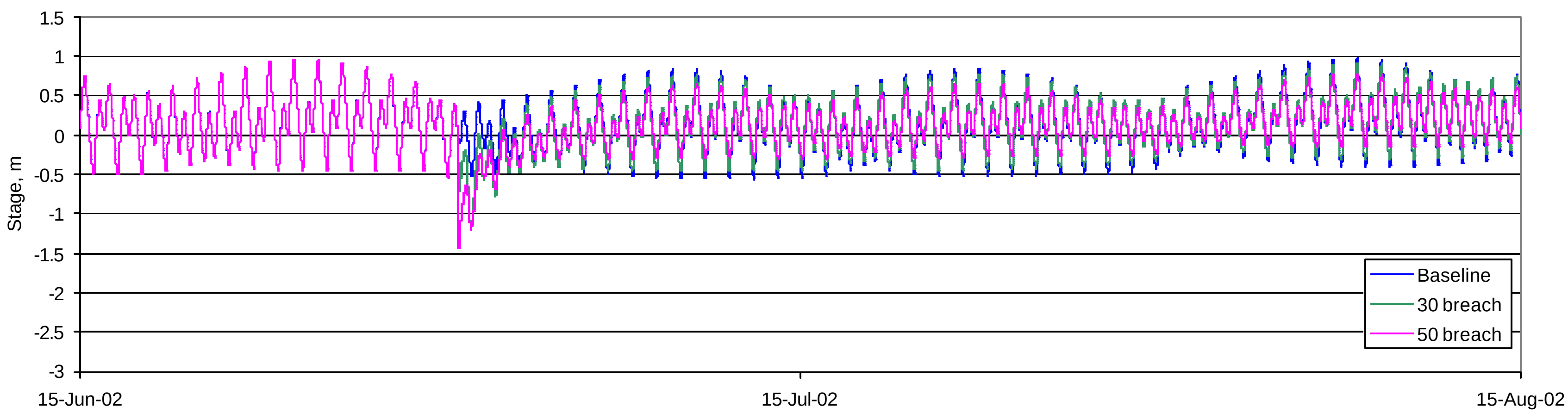

Figure 3-7 Stage time series in Sacramento River at Three Mile Slough.

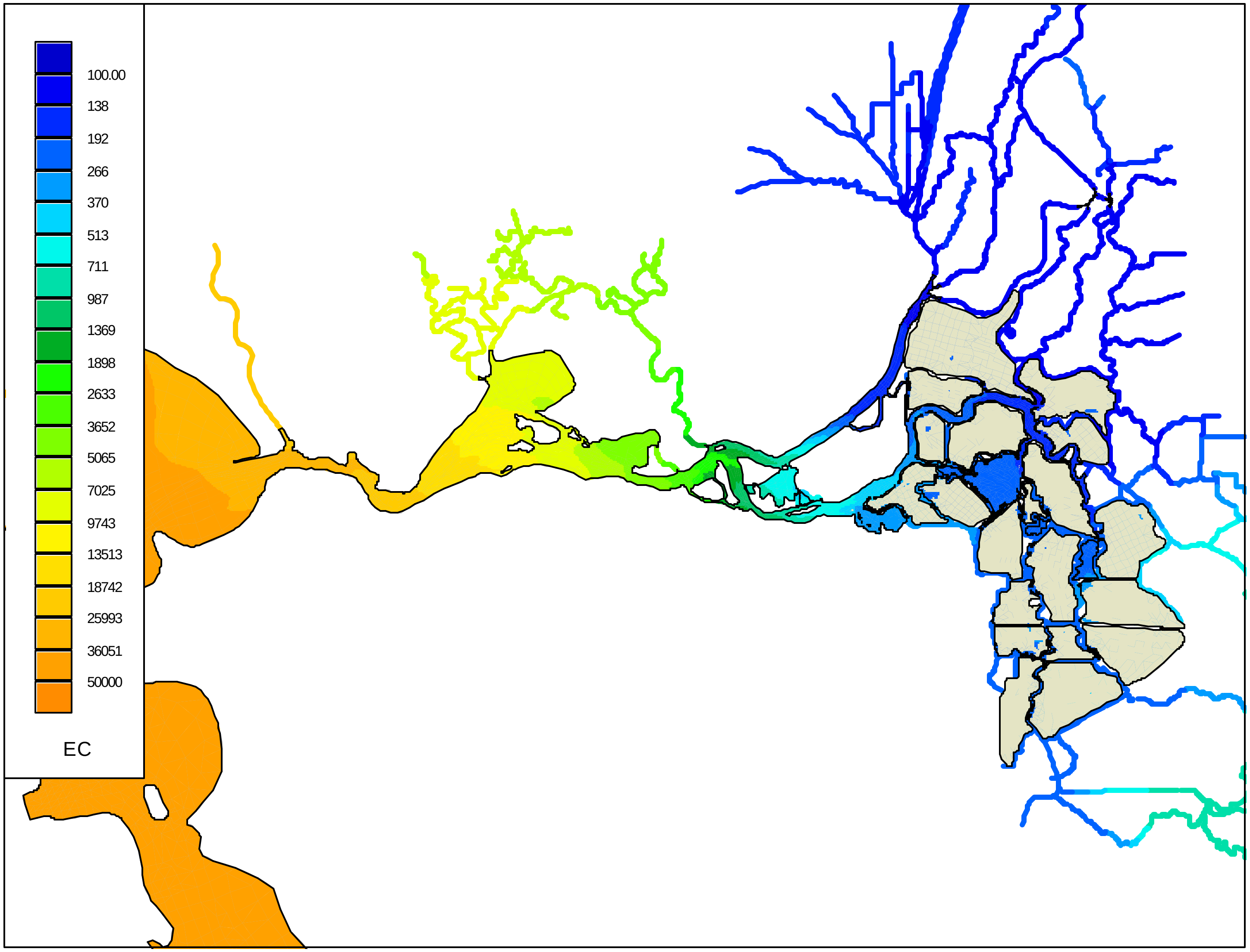

Figure 3-8 EC contour plot for 30 breach case on July 1, 2002, hour 0000 (just before breach event occurs).

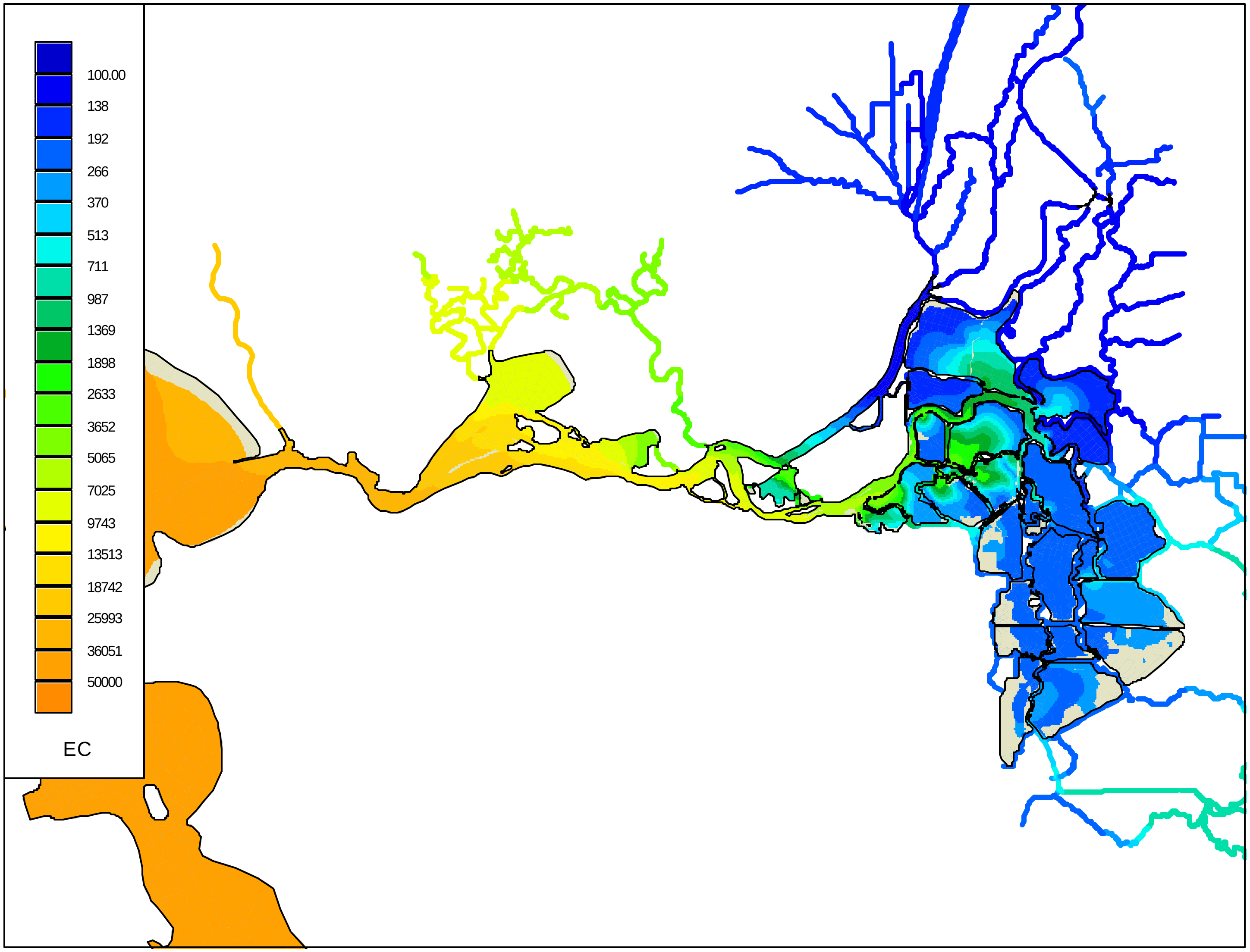

Figure 3-9 EC contour plot for 30 breach case on July 1, 2002, hour 1200.

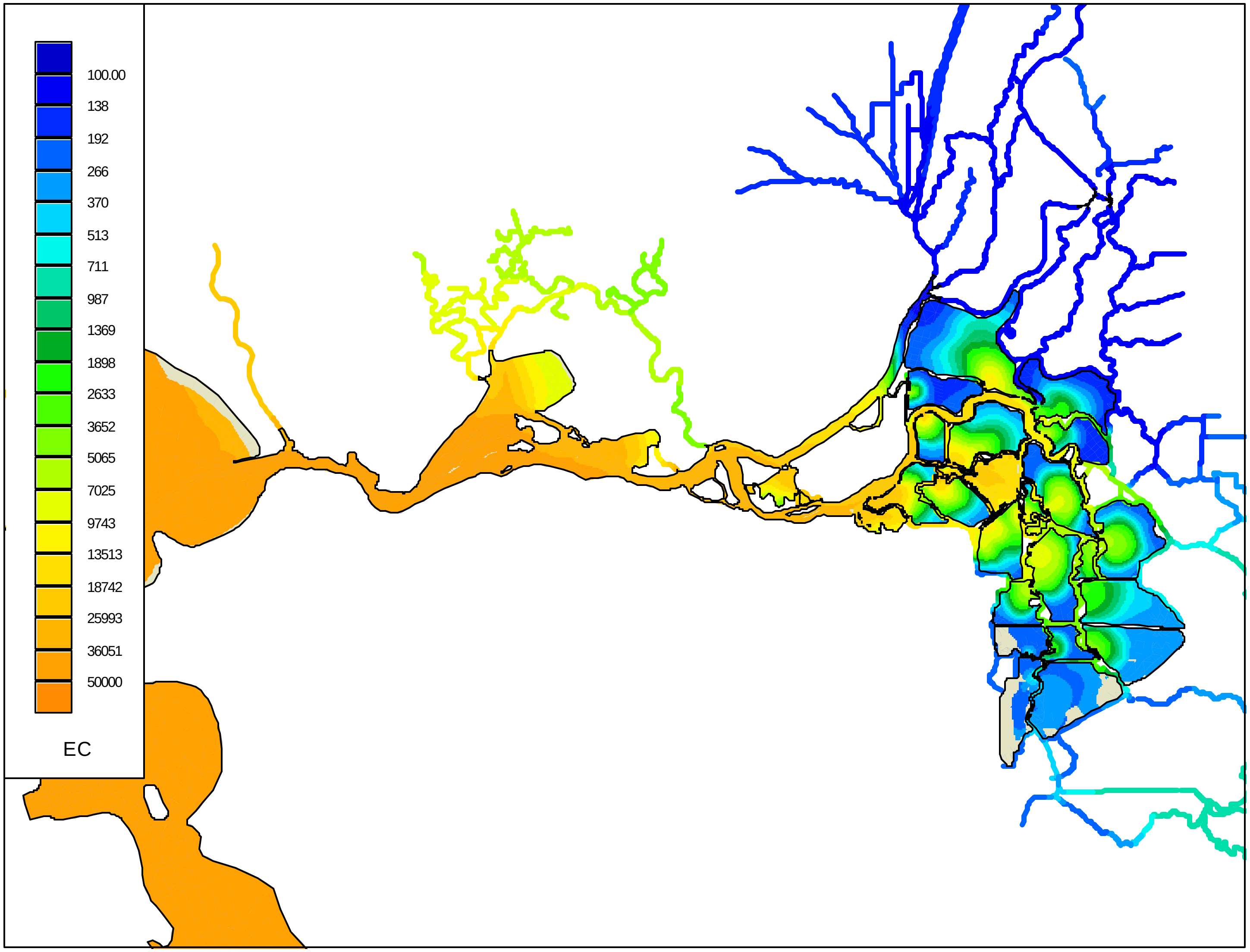

Figure 3-10 EC contours for 30 breach case on July 2, 2002, hour 1200.

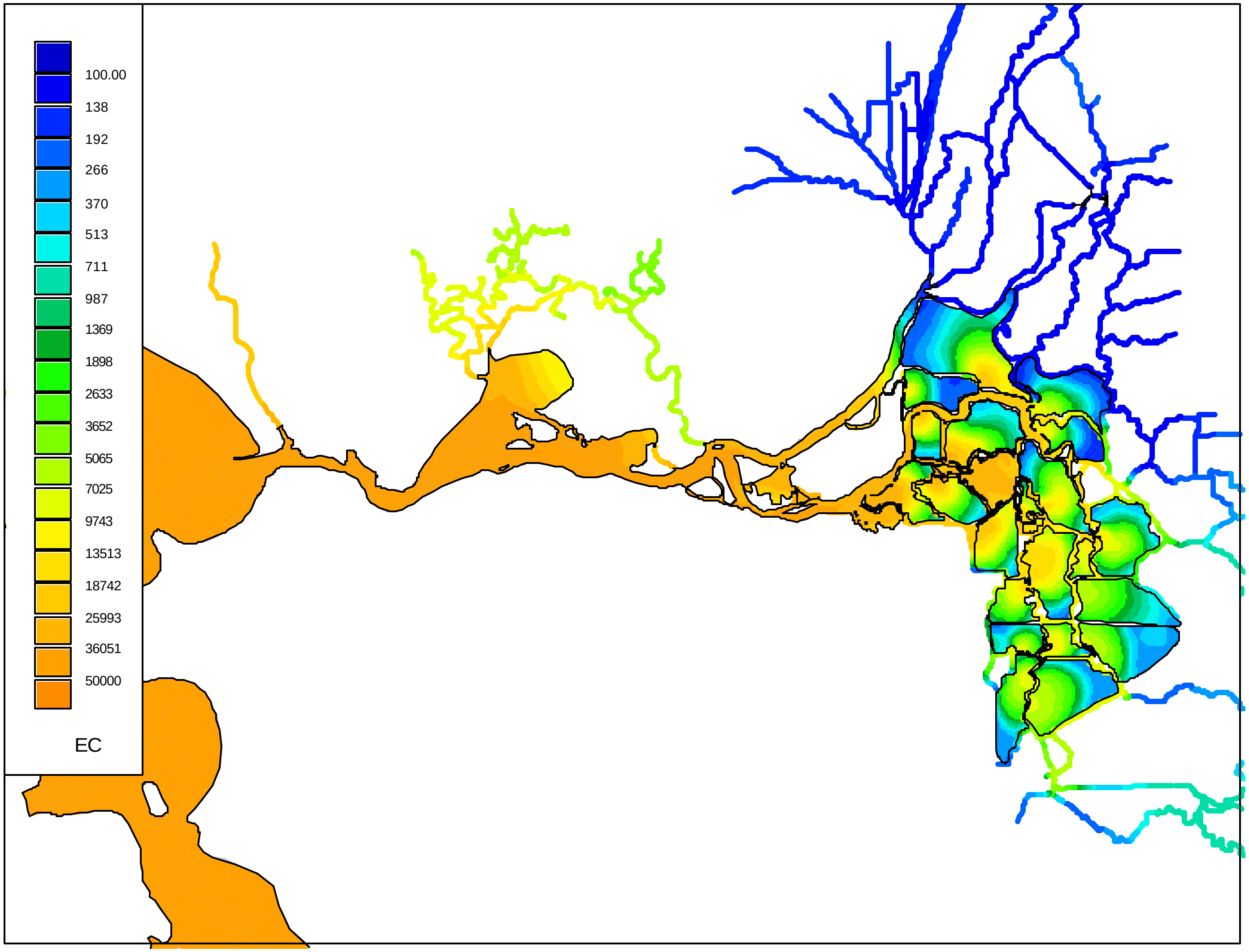

Figure 3-11 EC contours for 30 breach case on July 3, 2002, hour 1200.

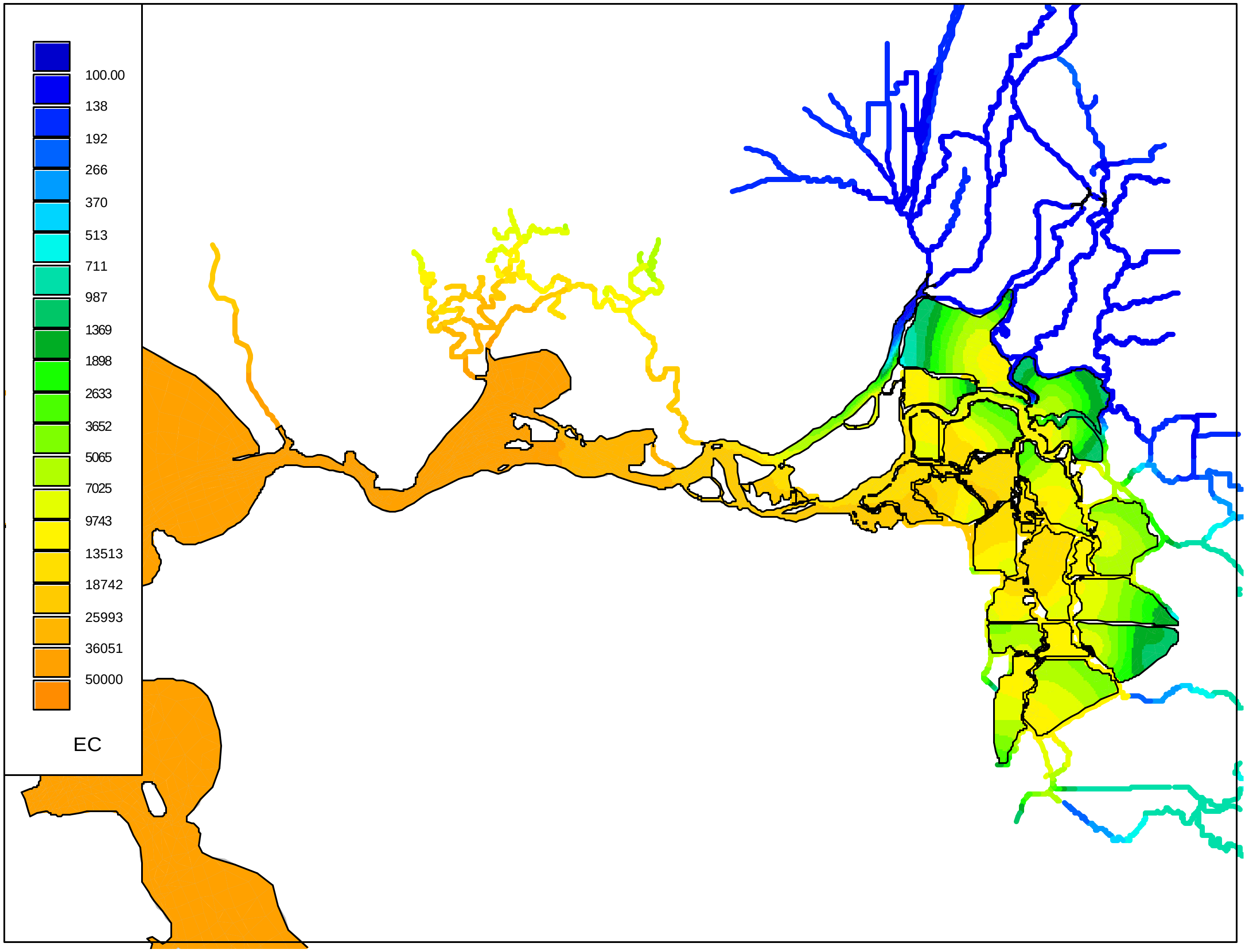

Figure 3-12 EC contours for 30 breach case on July 12, 2002, hour 0000.

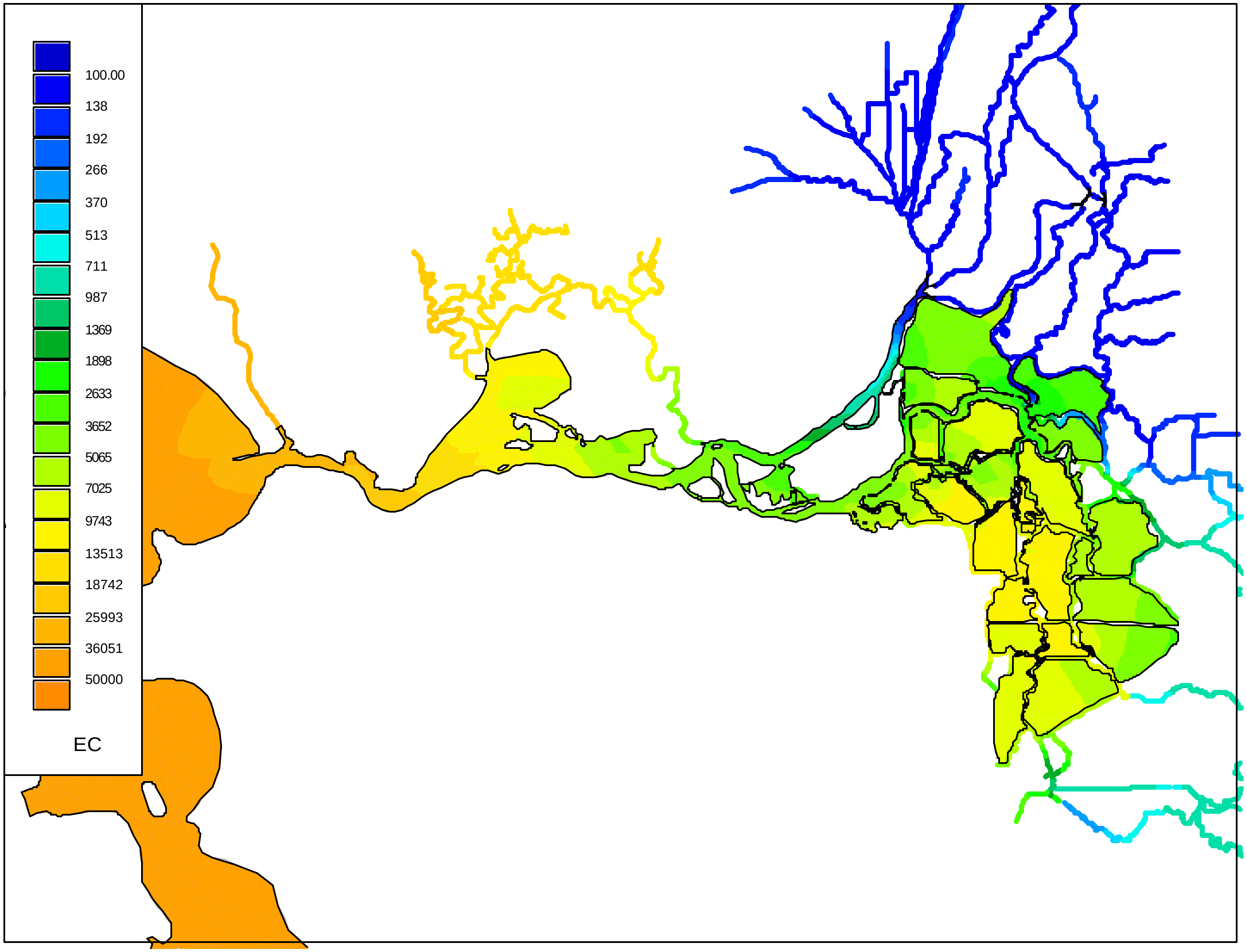

Figure 3-13 EC contours for 30 breach case on August 1, 2002, hour 0000.

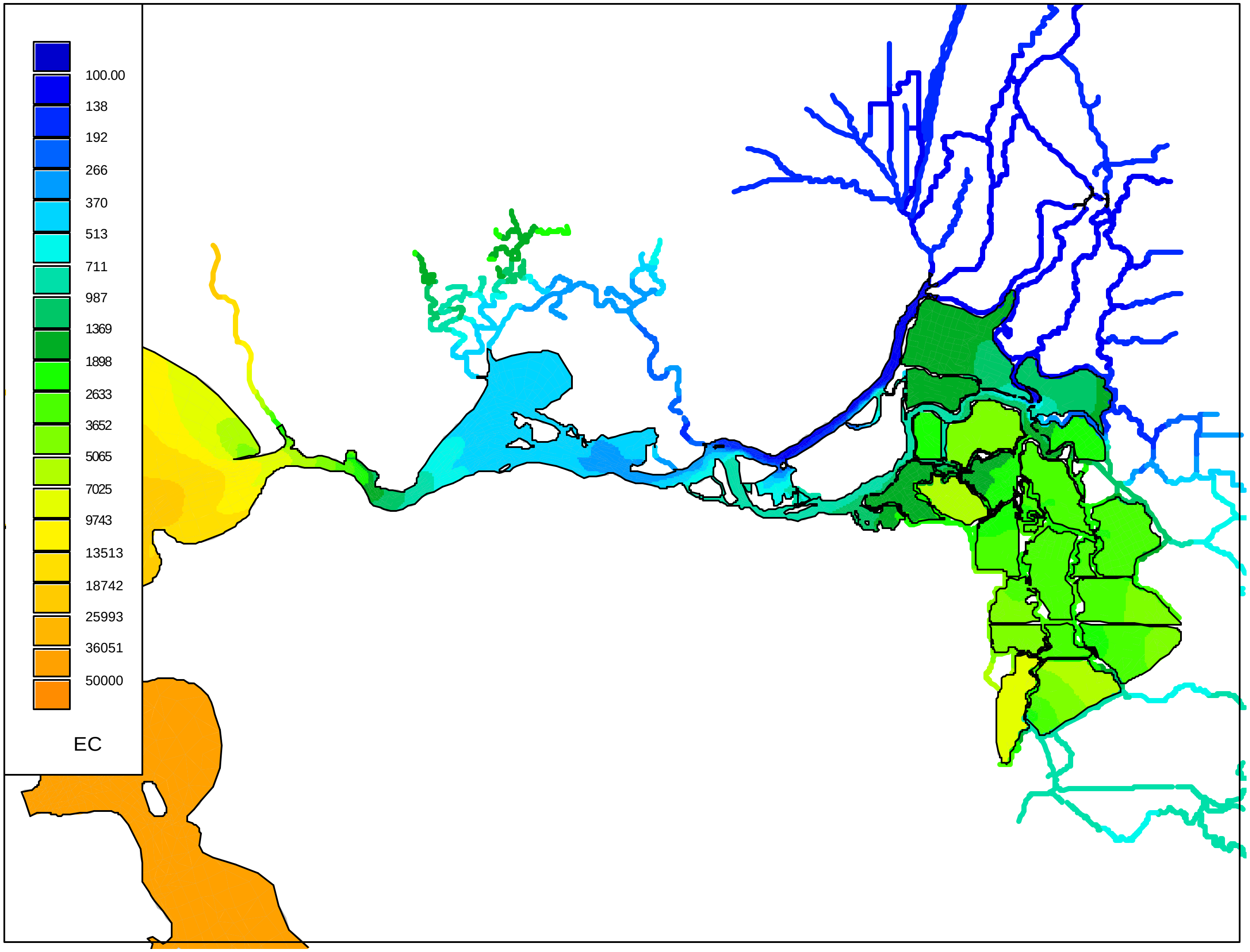

Figure 3-14 EC contours for 30 breach case on January 1, 2003, hour 0000.

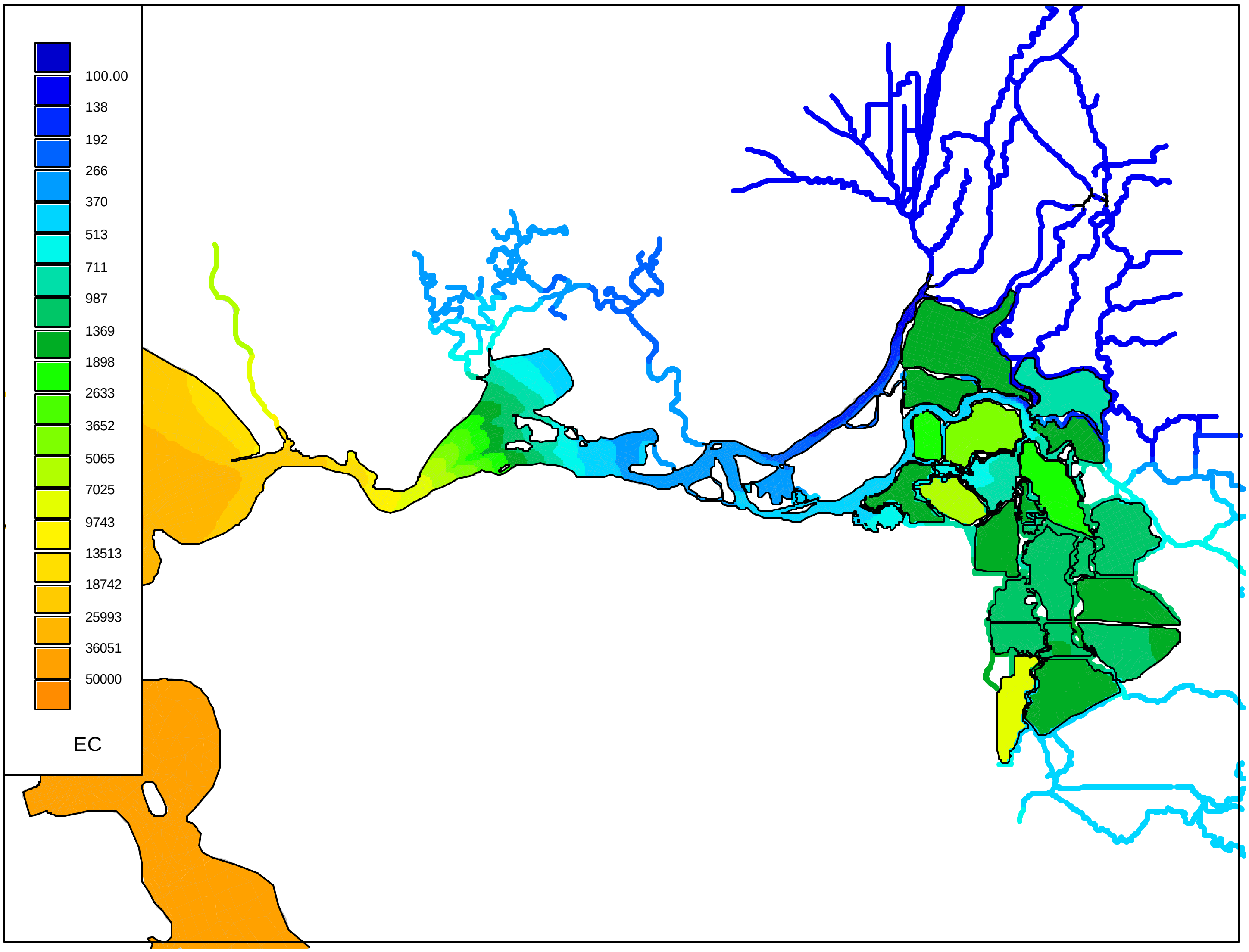

Figure 3-15 EC contours for 30 breach case on July 1, 2003, hour 0000.

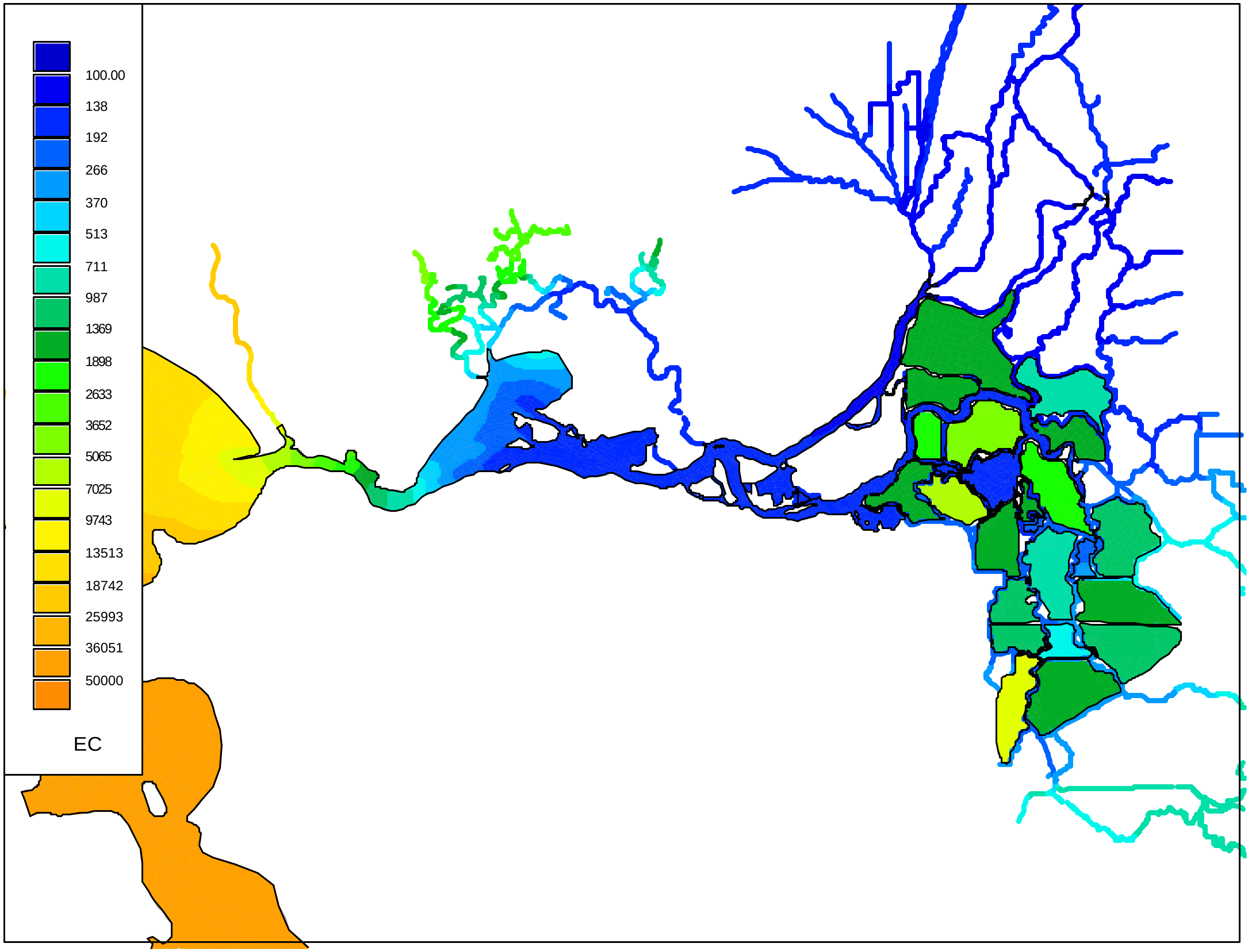

Figure 3-16 EC contours for 30 breach case on January 1, 2004, hour 0000.

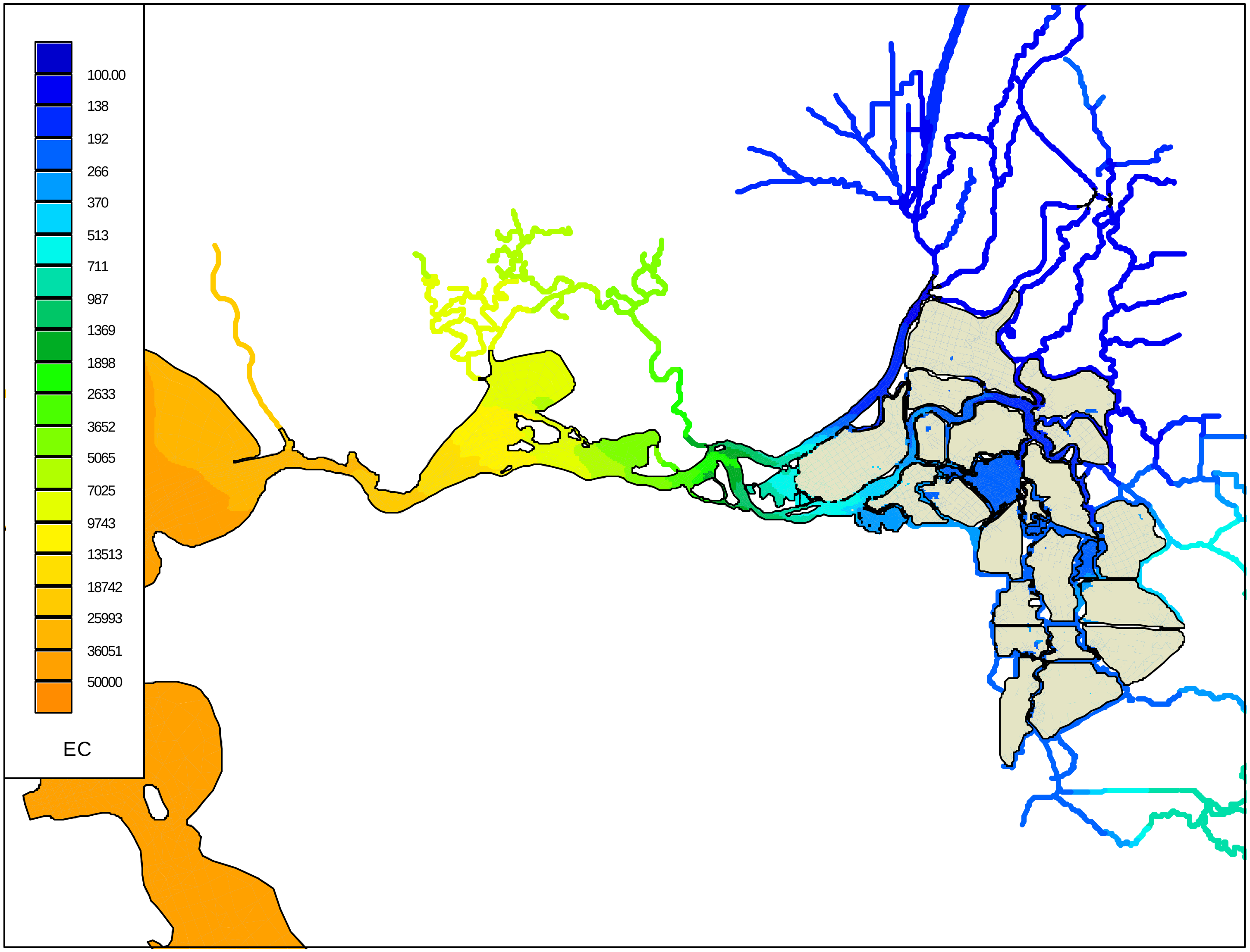

Figure 3-17 EC contour plot for 50 breach case on July 1, 2002, hour 0000 (just before breach event occurs).

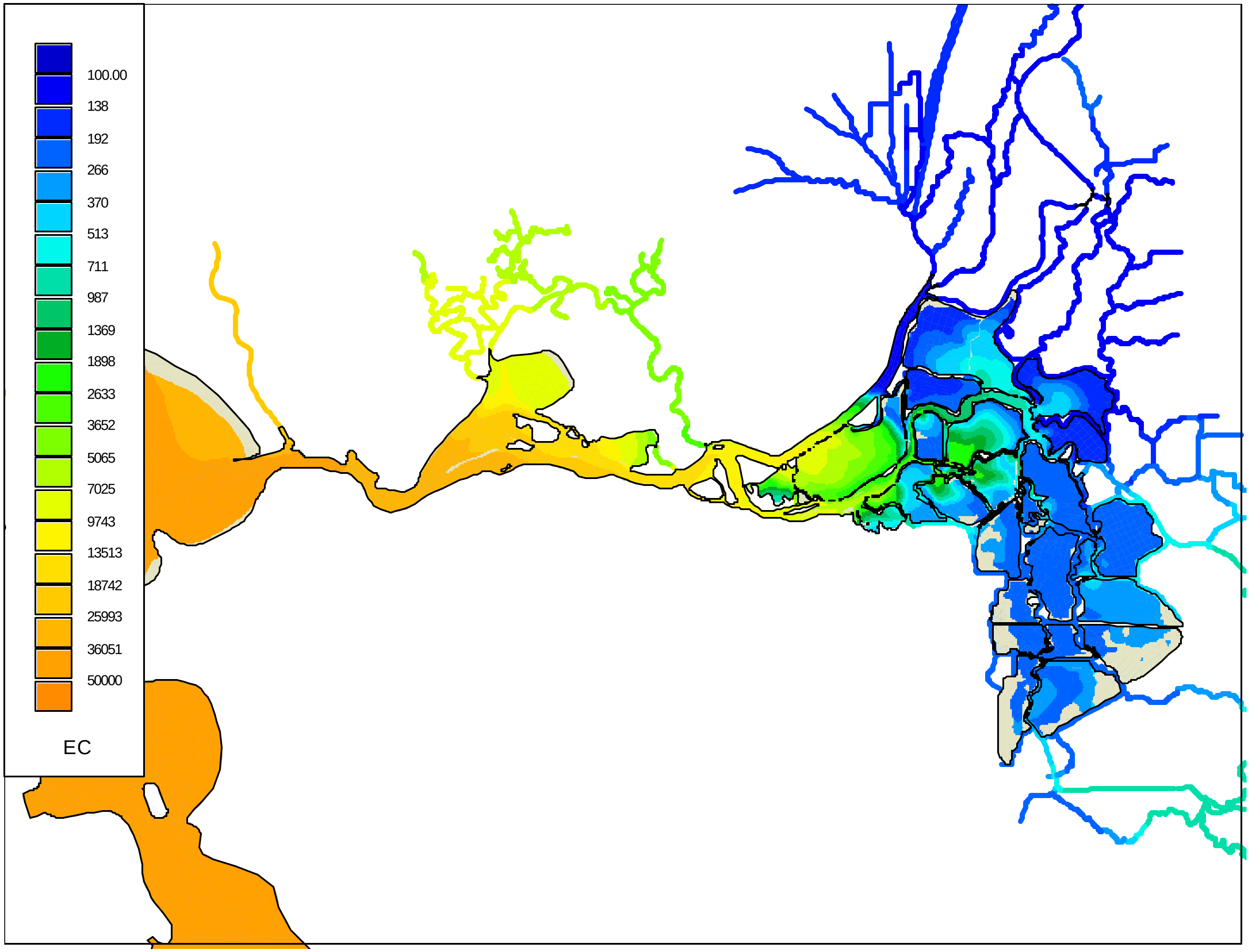

Figure 3-18 EC contour plot for 50 breach case on July 1, 2002, hour 1200.

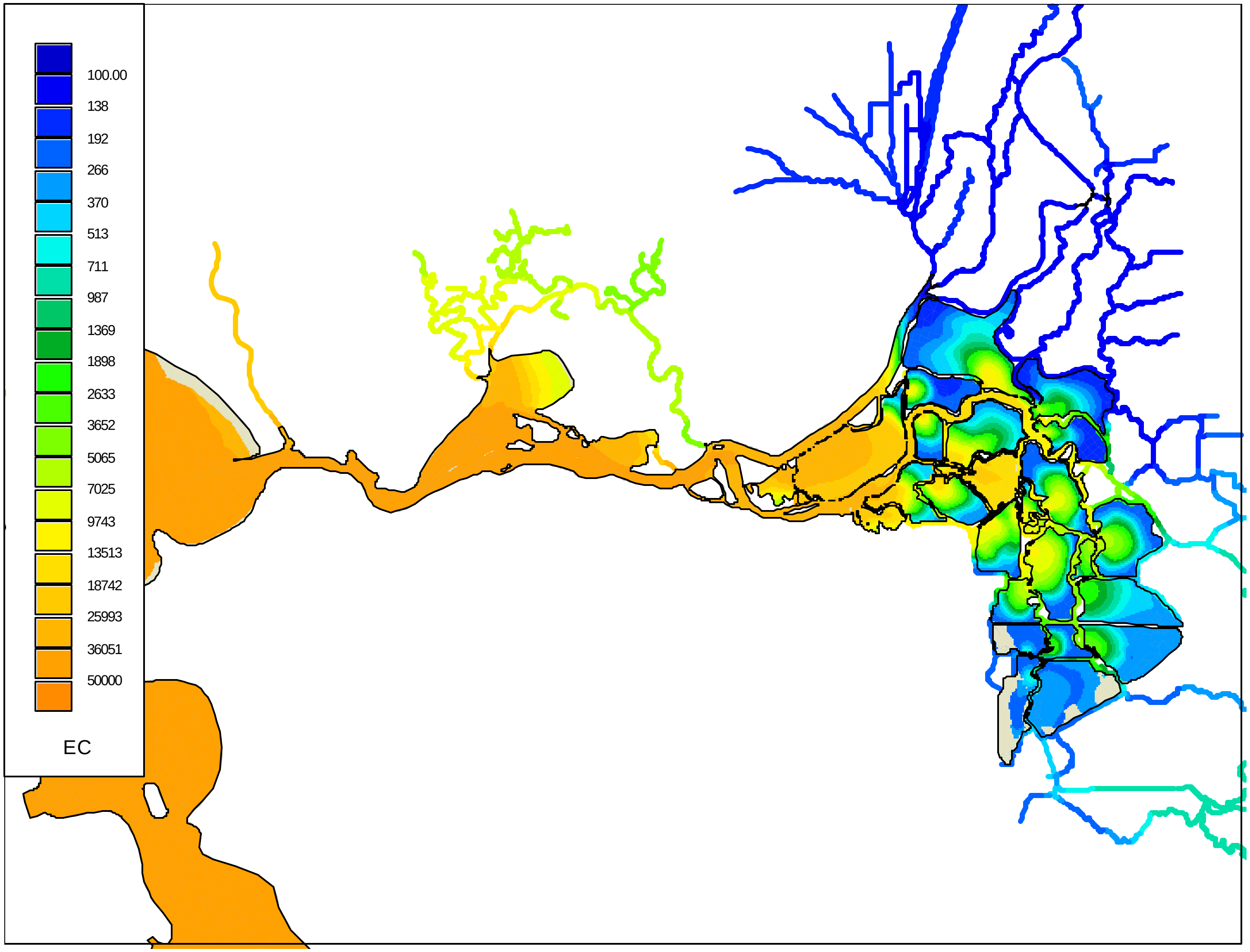

Figure 3-19 EC contours for 50 breach case on July 2, 2002, hour 1200.

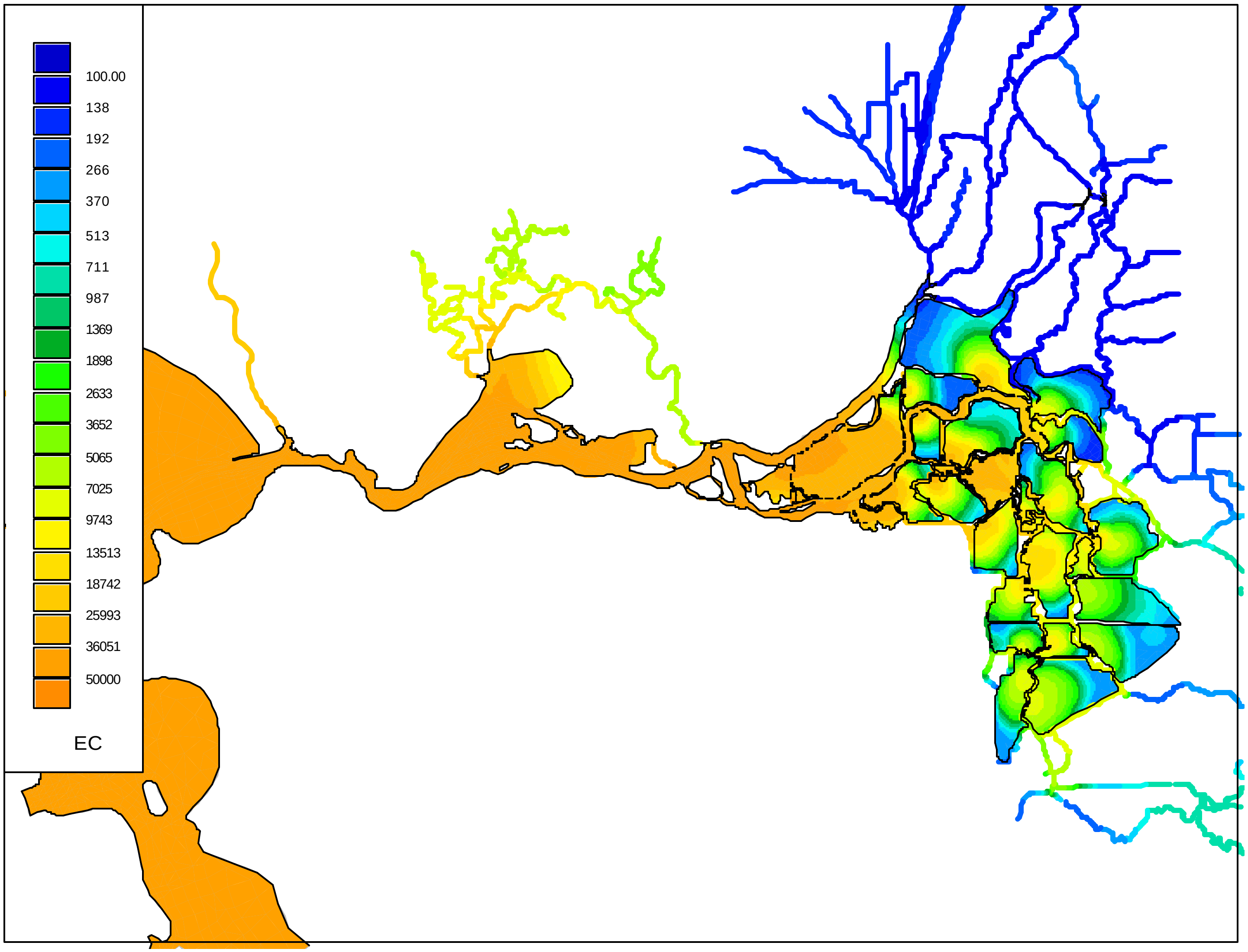

Figure 3-20 EC contours for 50 breach case on July 3, 2002, hour 1200.

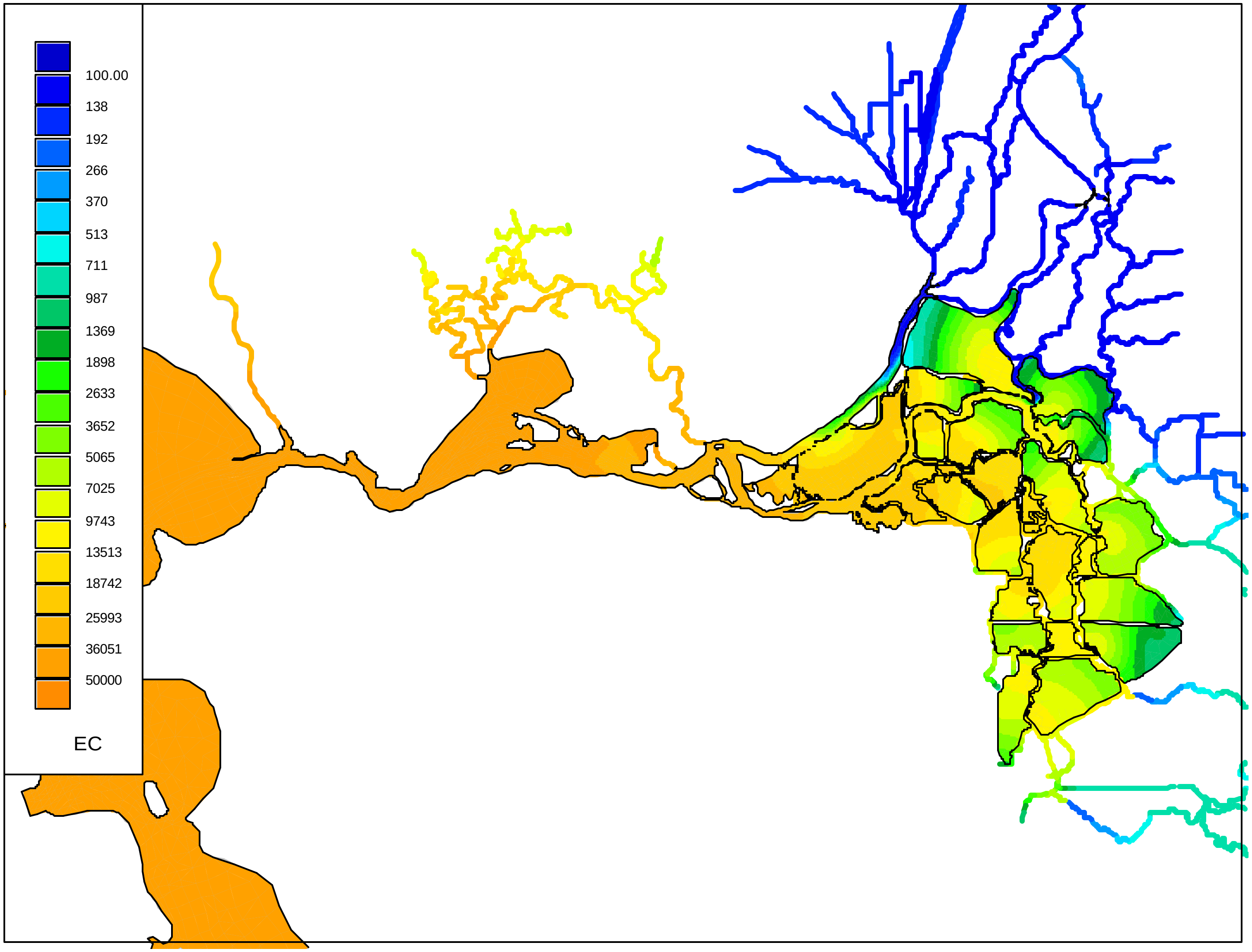

Figure 3-21 EC contours for 50 breach case on July 12, 2002, hour 0000.

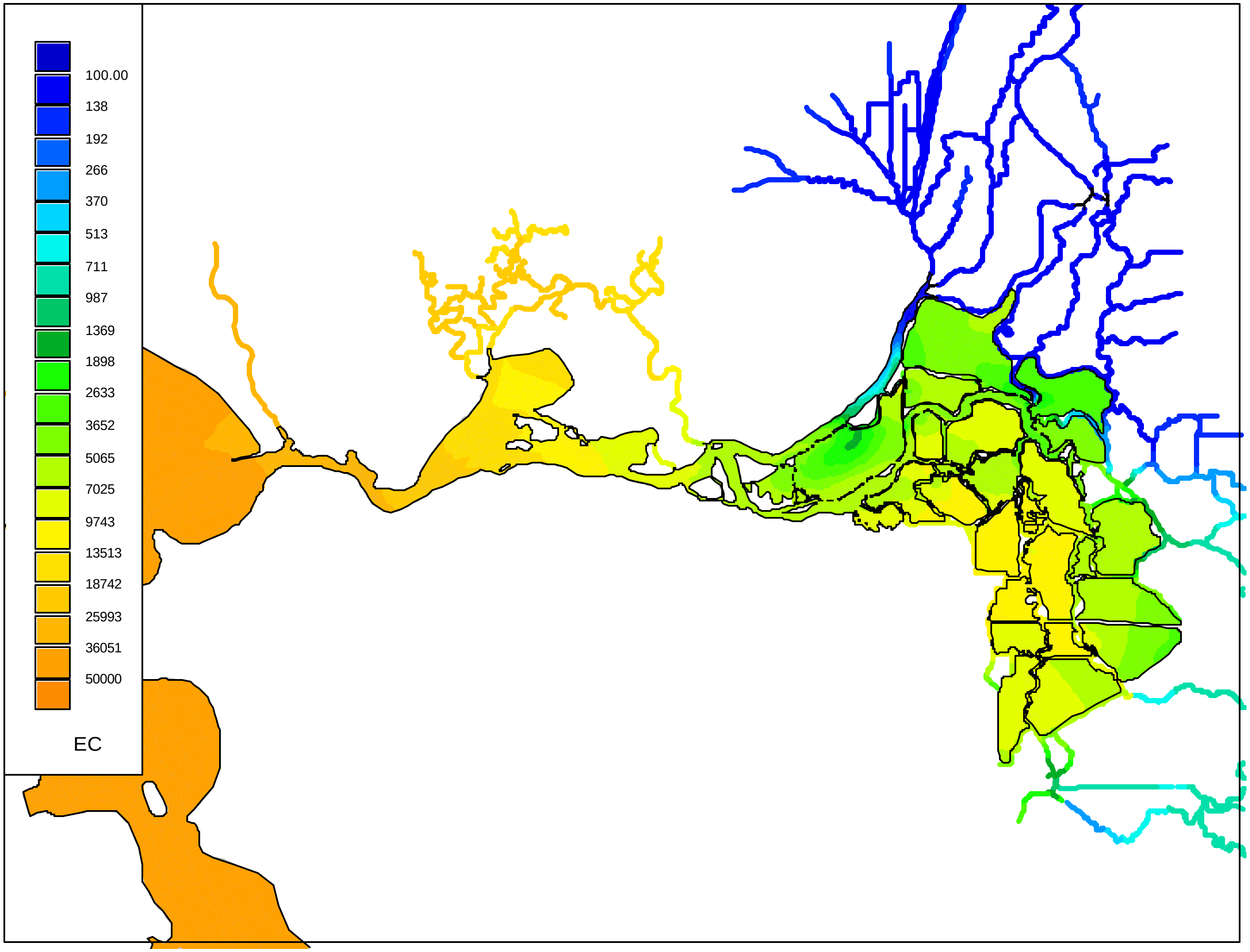

Figure 3-22 EC contours for 50 breach case on August 1, 2002, hour 0000.

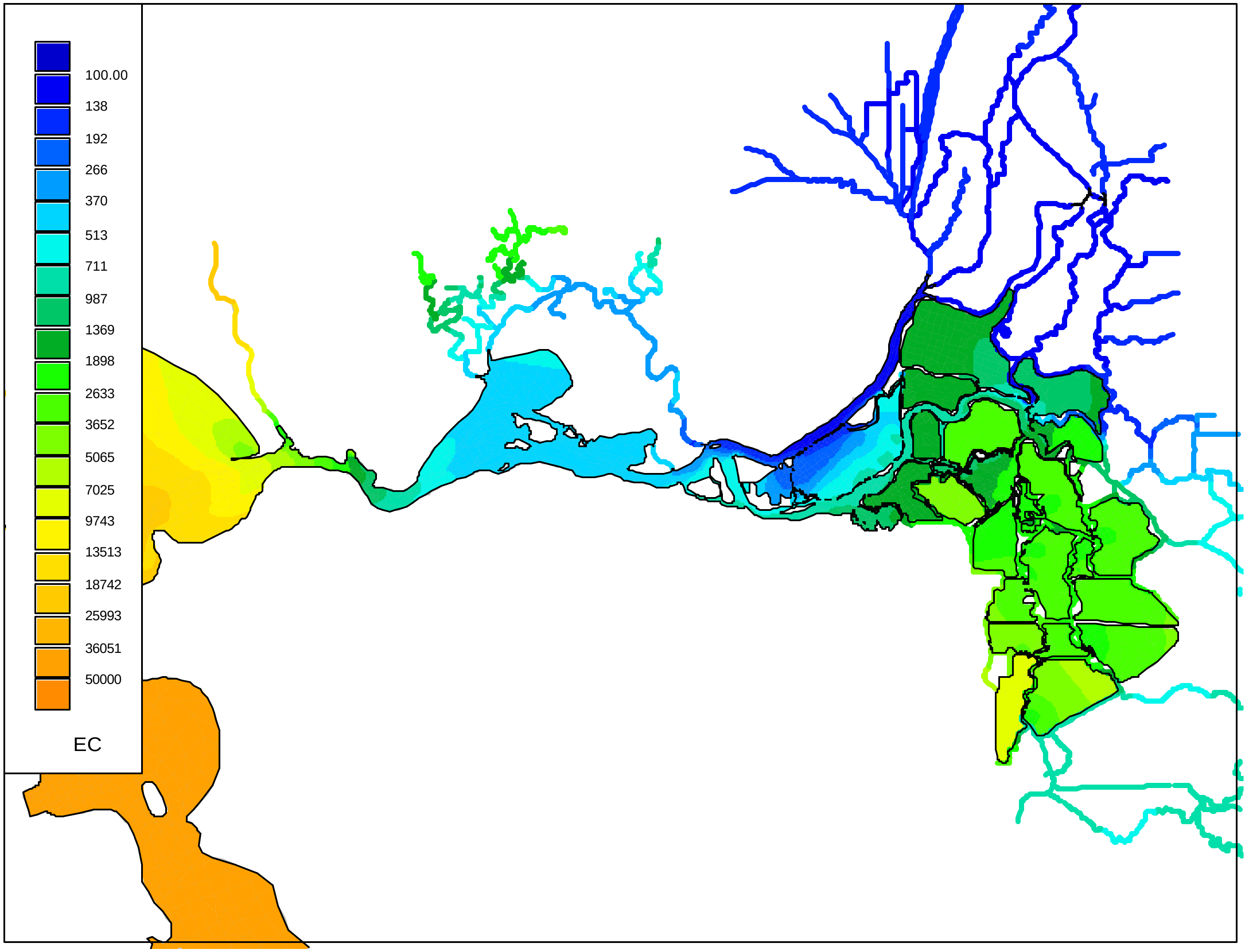

Figure 3-23 EC contours for 50 breach case on January 1, 2003, hour 0000.

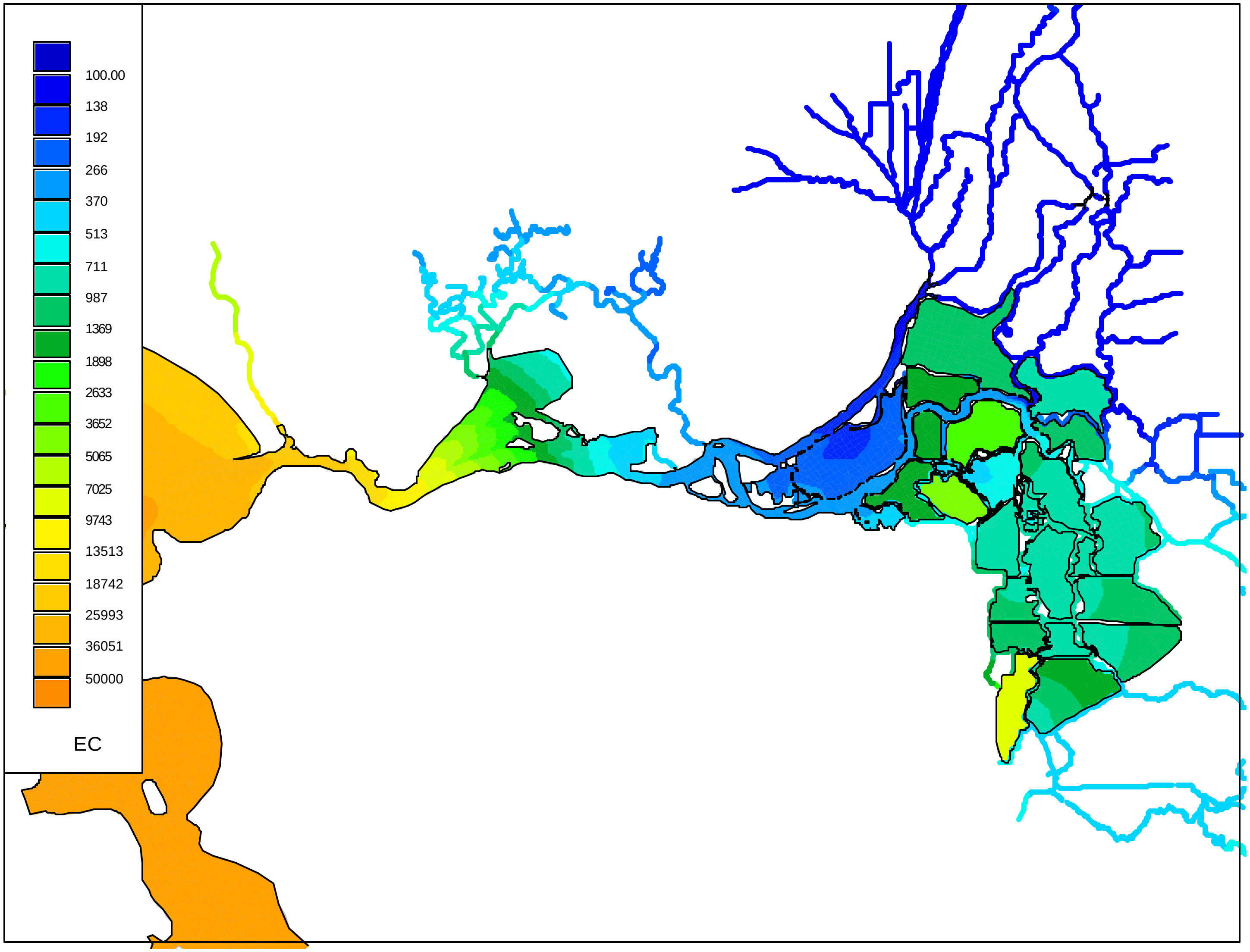

Figure 3-24 EC contours for 50 breach case on July 1, 2003, hour 0000.

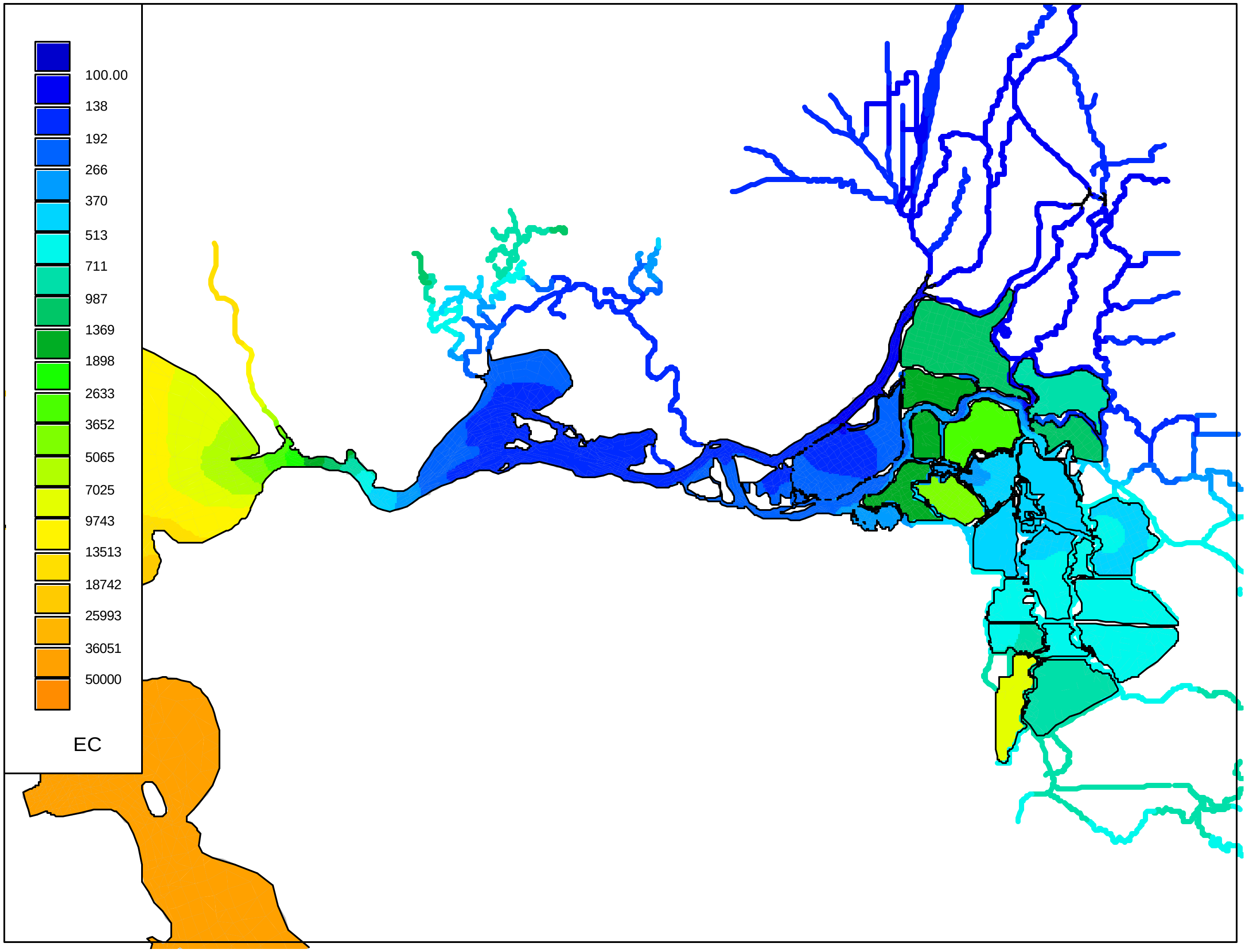

Figure 3-25 EC contours for 50 breach case on January 1, 2004, hour 0000.

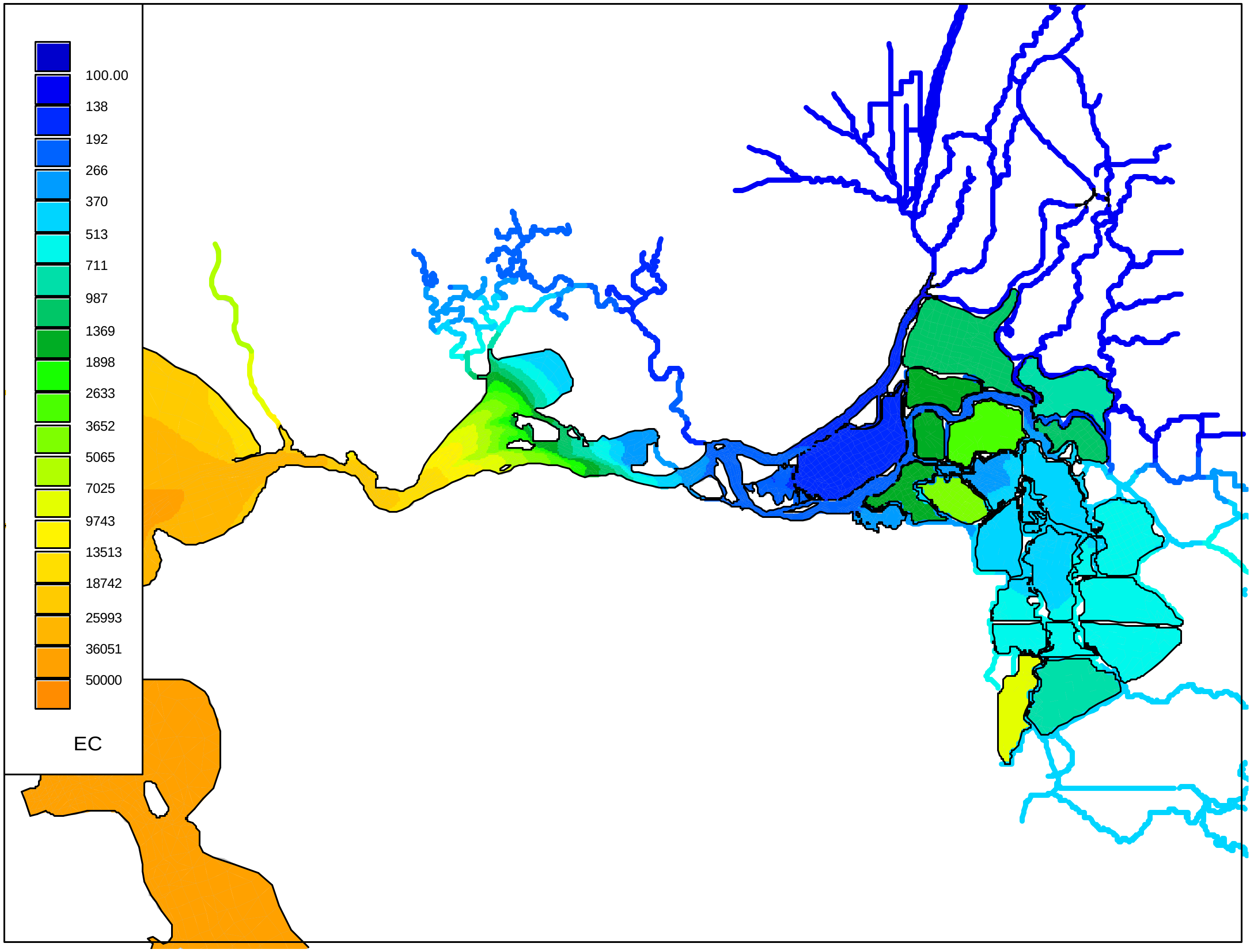

Figure 3-26 EC contours for 50 breach case on July 1, 2004, hour 0000.

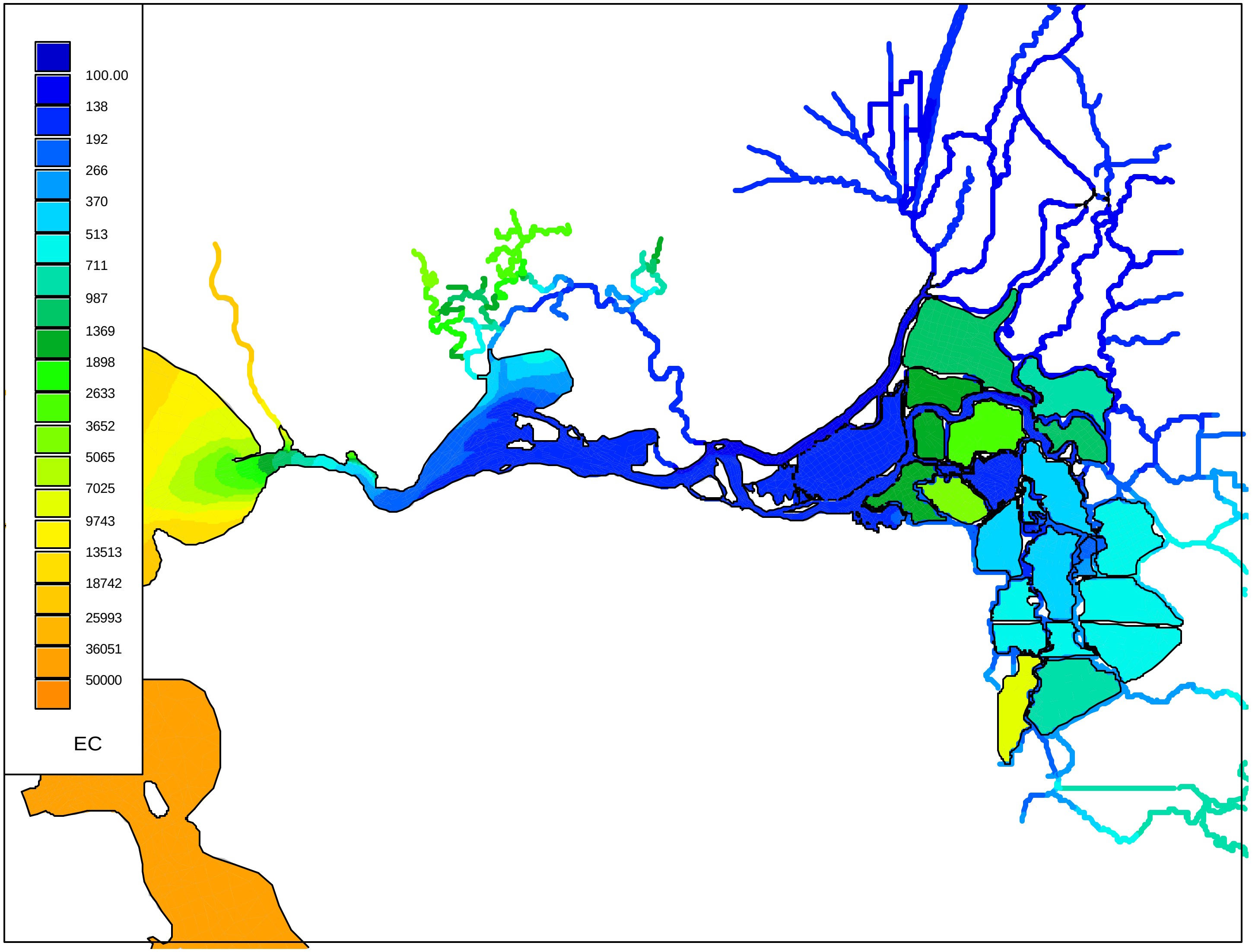

Figure 3-27 EC contours for 50 breach case on January 1, 2005, hour 0000.

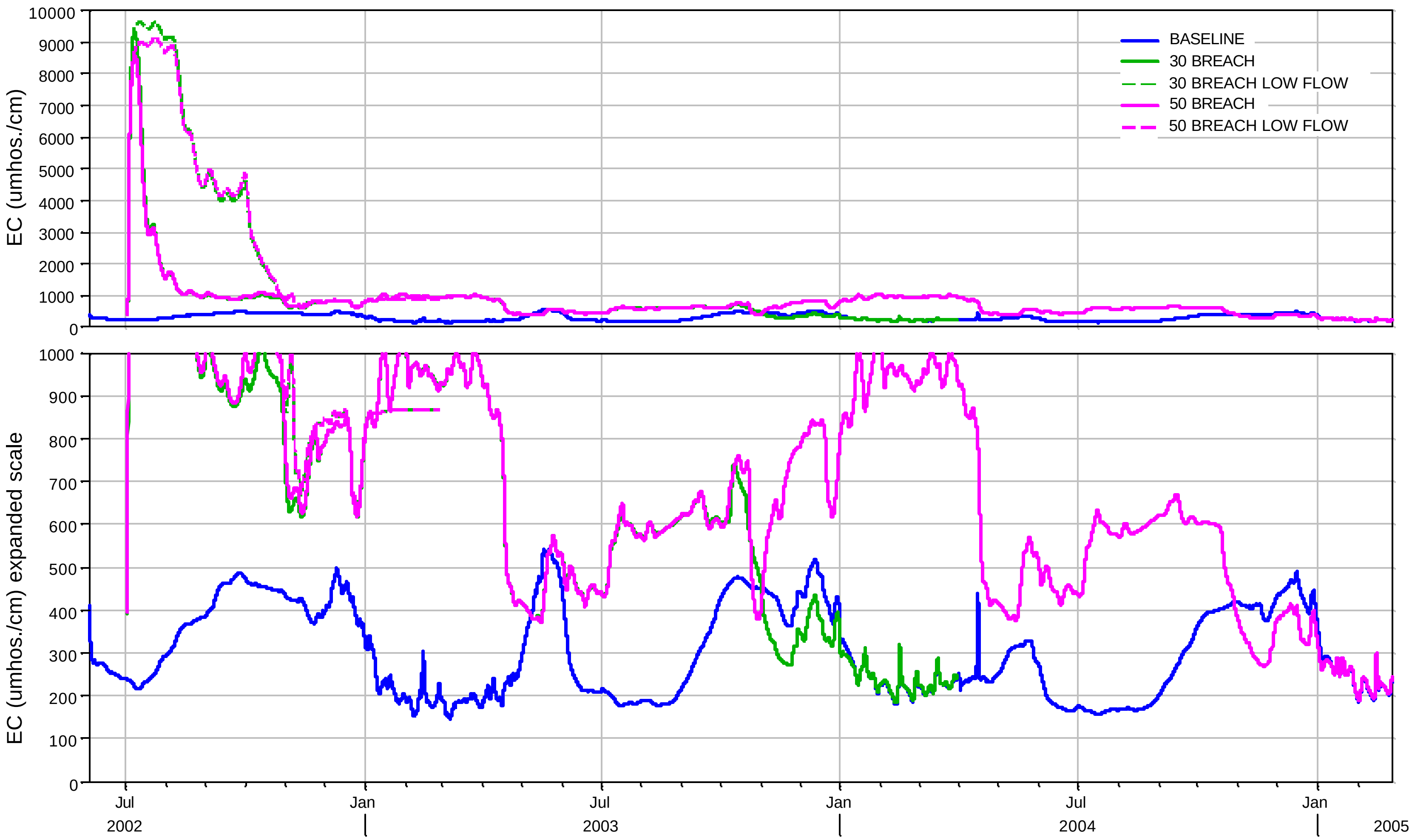

Figure 3-28 Tidally averaged EC time series at SWP.

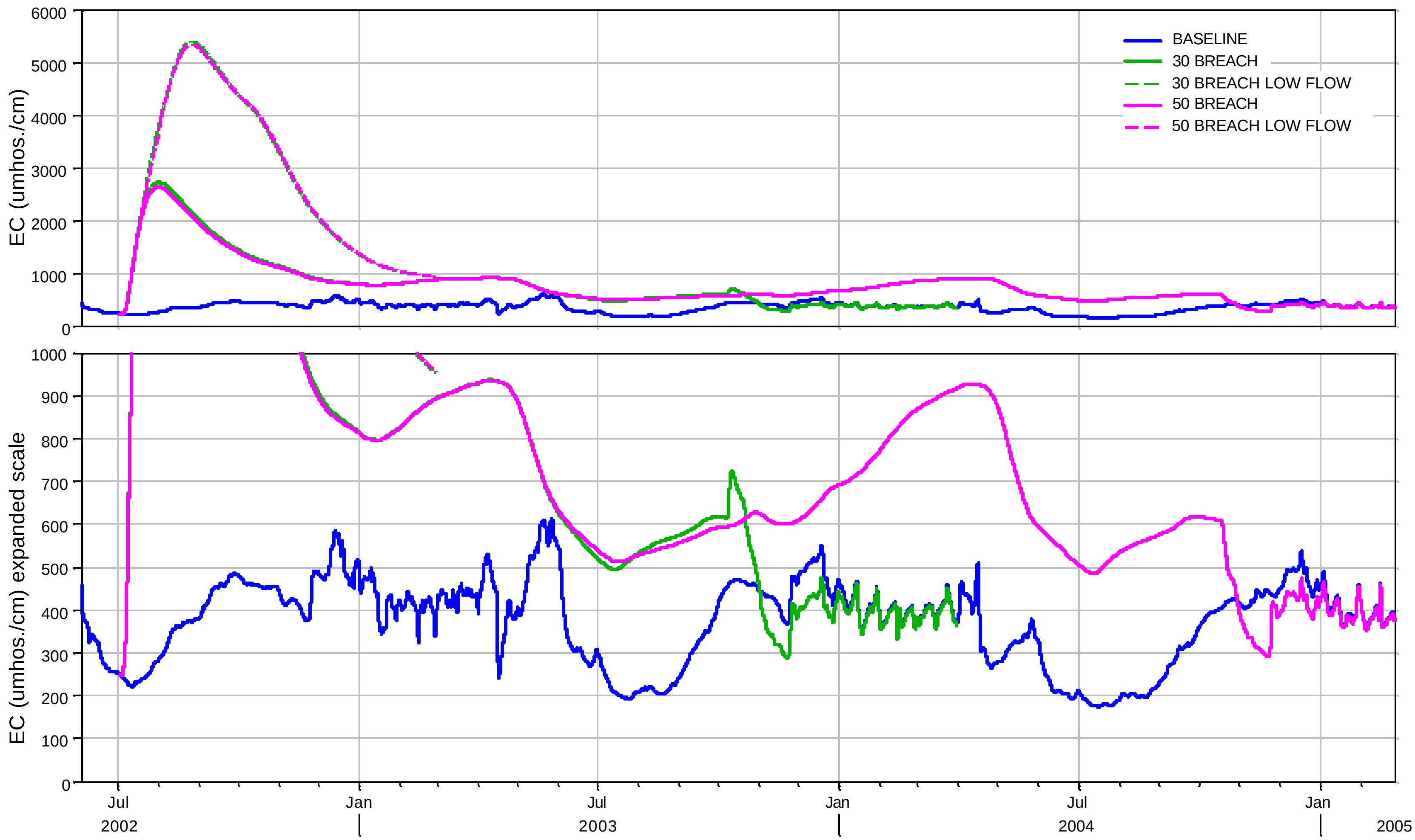

Figure 3-29 Tidally averaged EC time series at CVP.

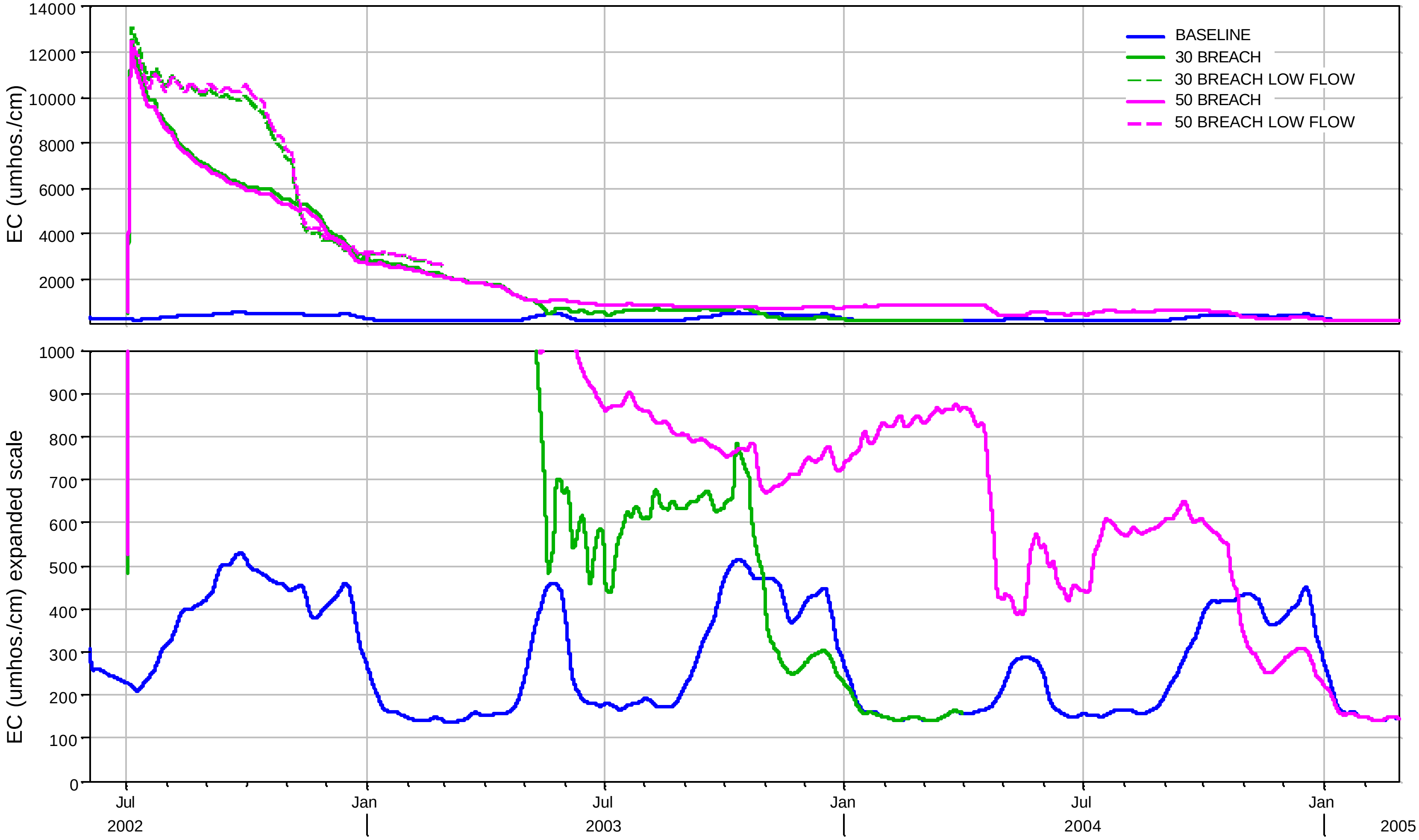

Figure 3-30 Tidally averaged EC time series at Contra Costa water intake at ROLD034.

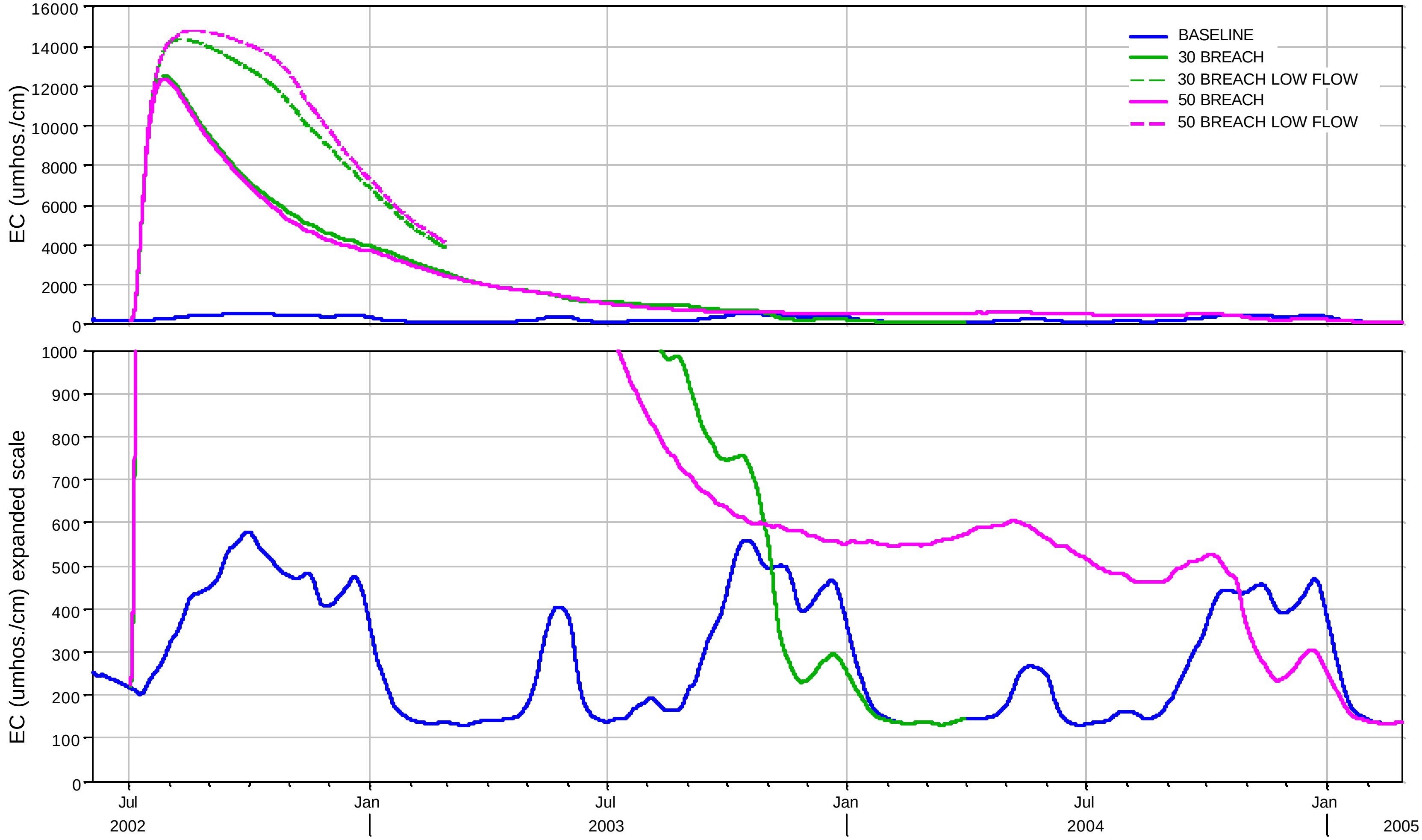

Figure 3-31 Tidally averaged EC time series at Contra Costa water intake in Rock Slough.

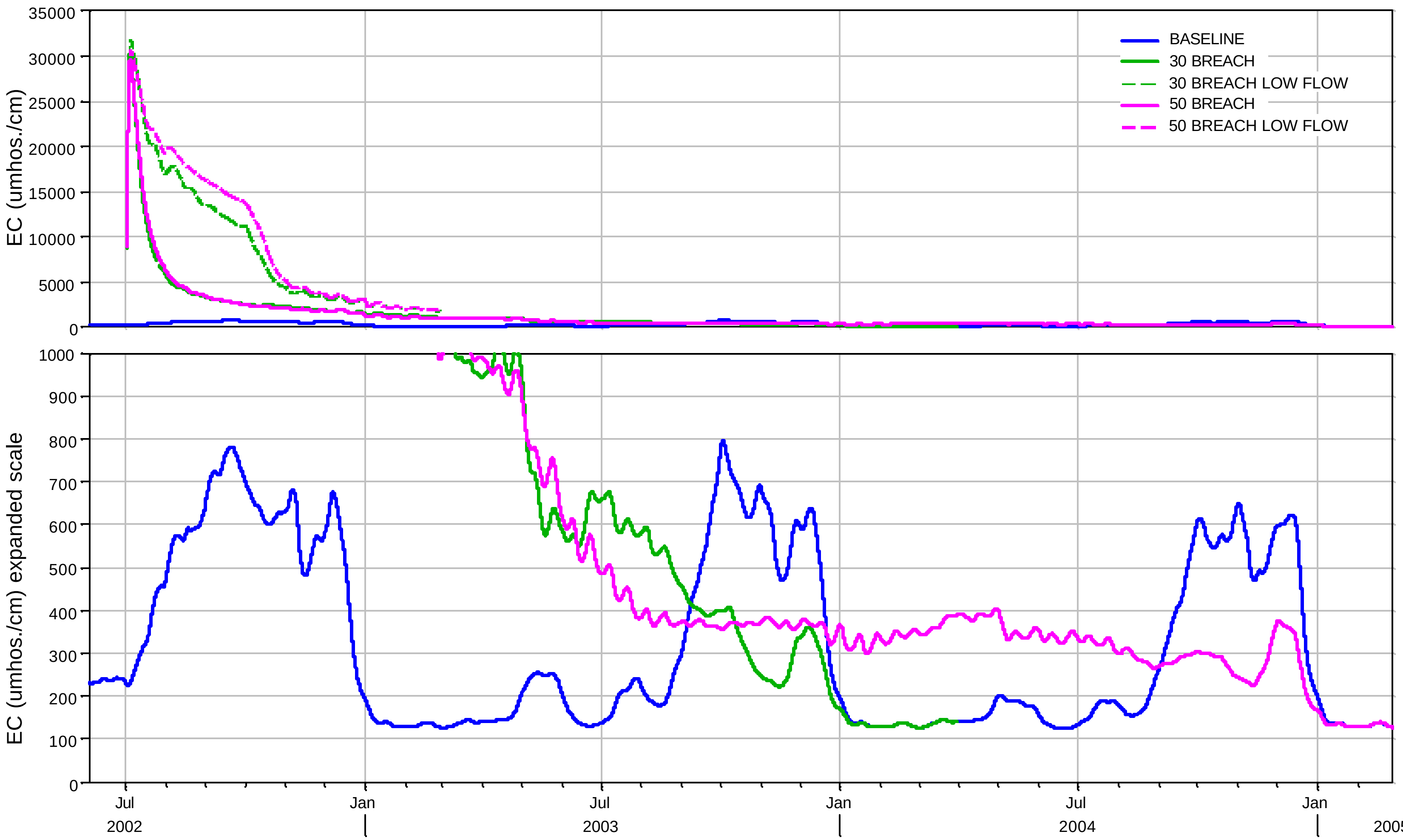

Figure 3-32 Tidally averaged EC time series at Frank's Tract

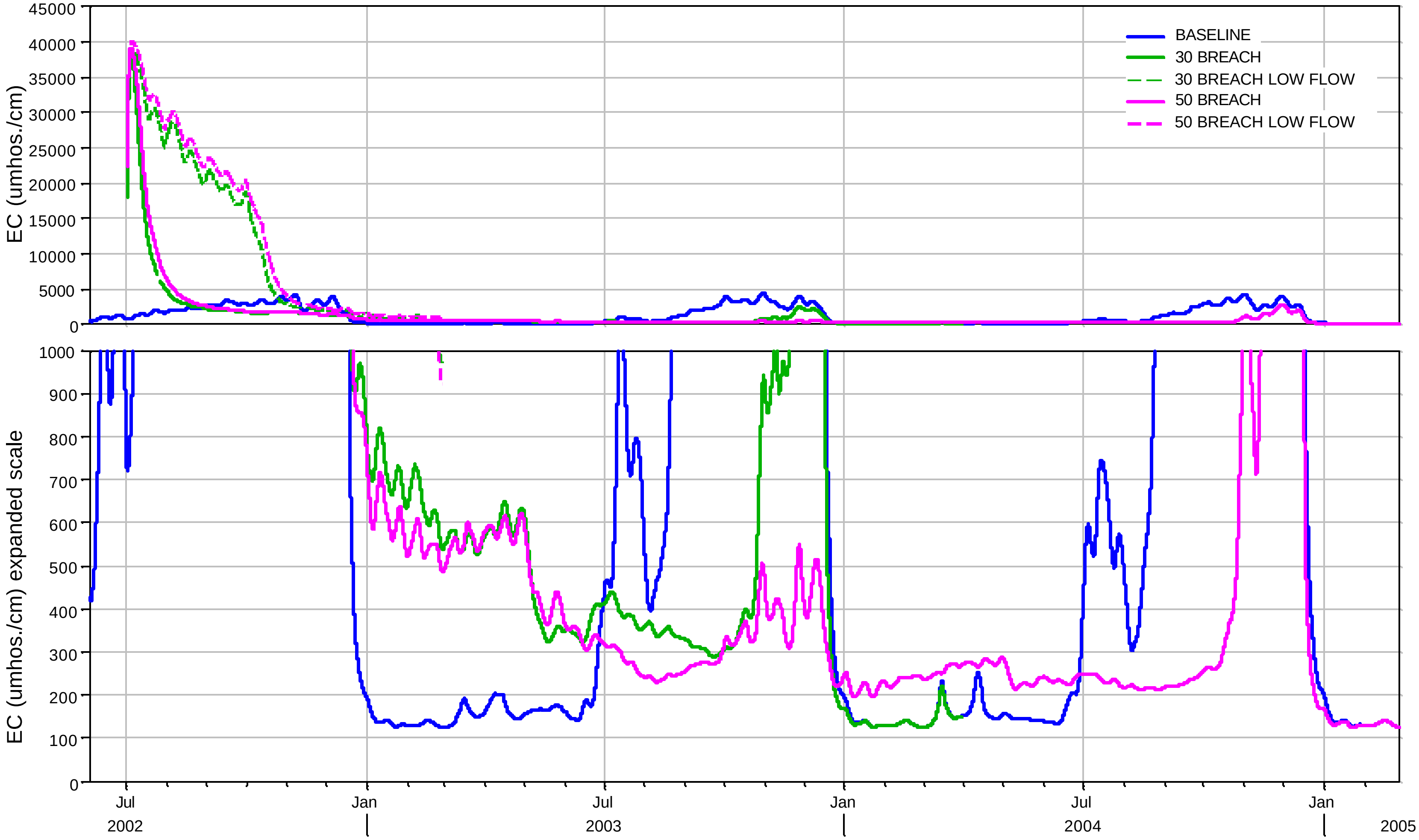

Figure 3-33 Tidally averaged EC time series at Antioch.

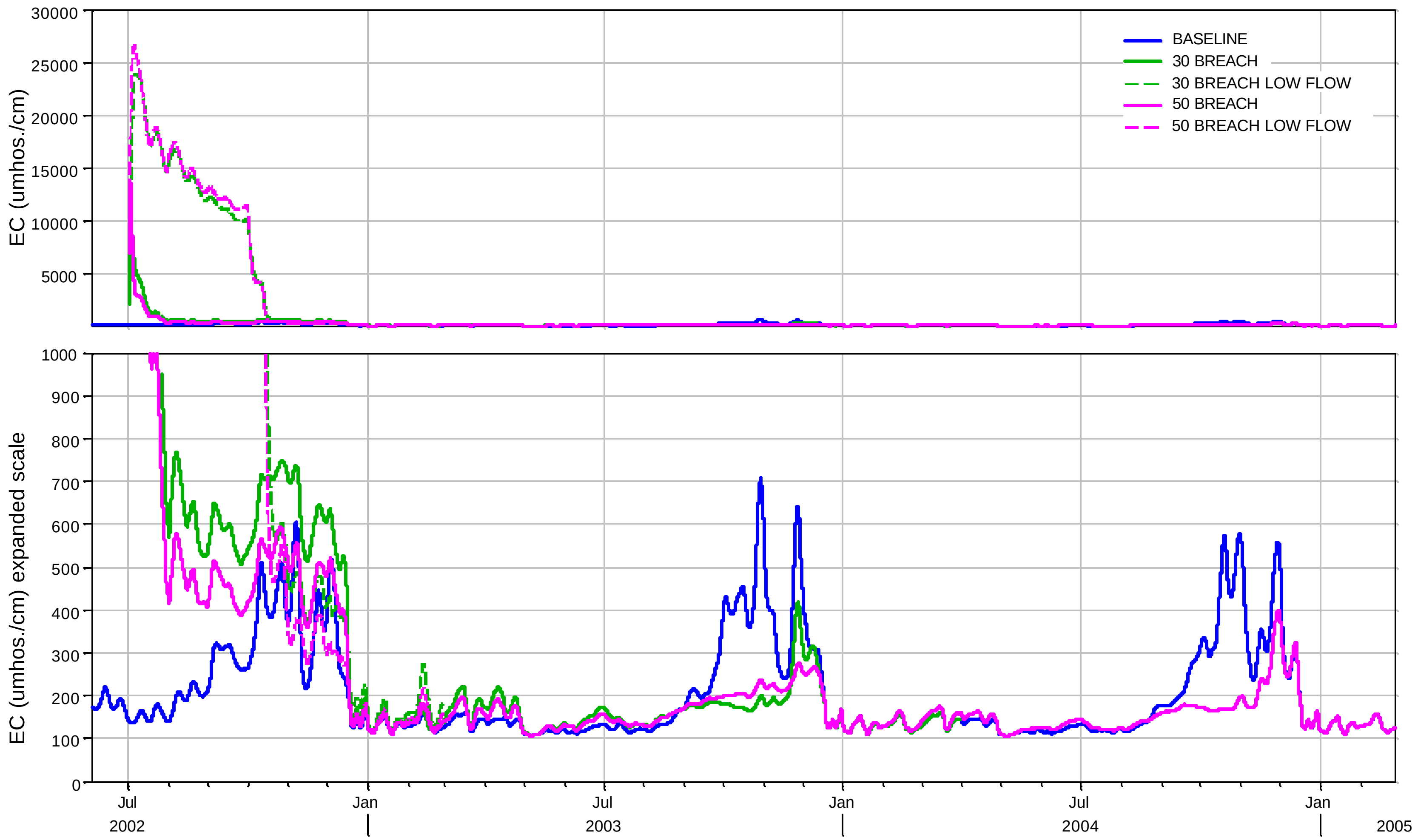

Figure 3-34 Tidally averaged EC time series in Sacramento River at Three Mile Slough.

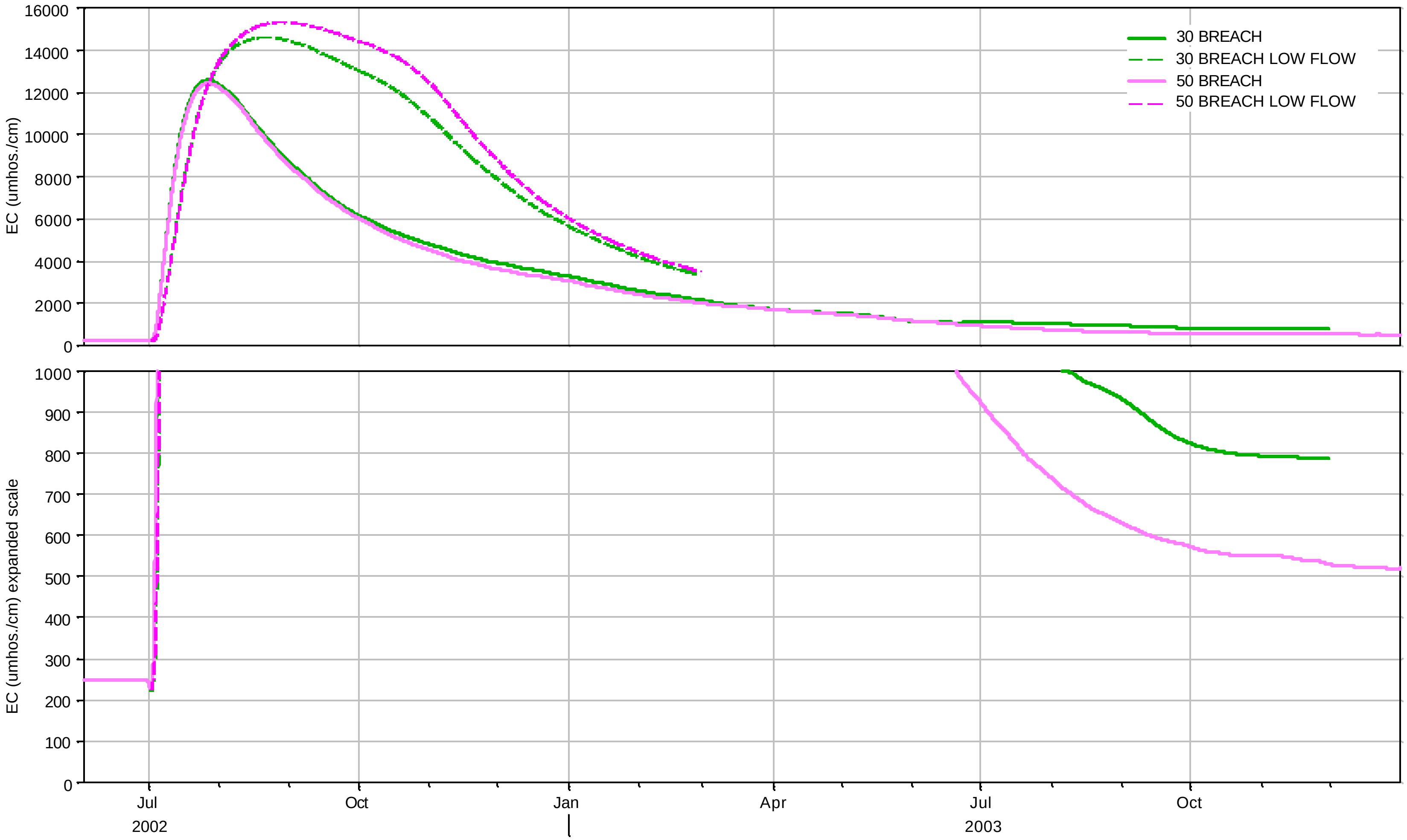

Figure 3-35 Tidally averaged EC time series in Bacon Island.

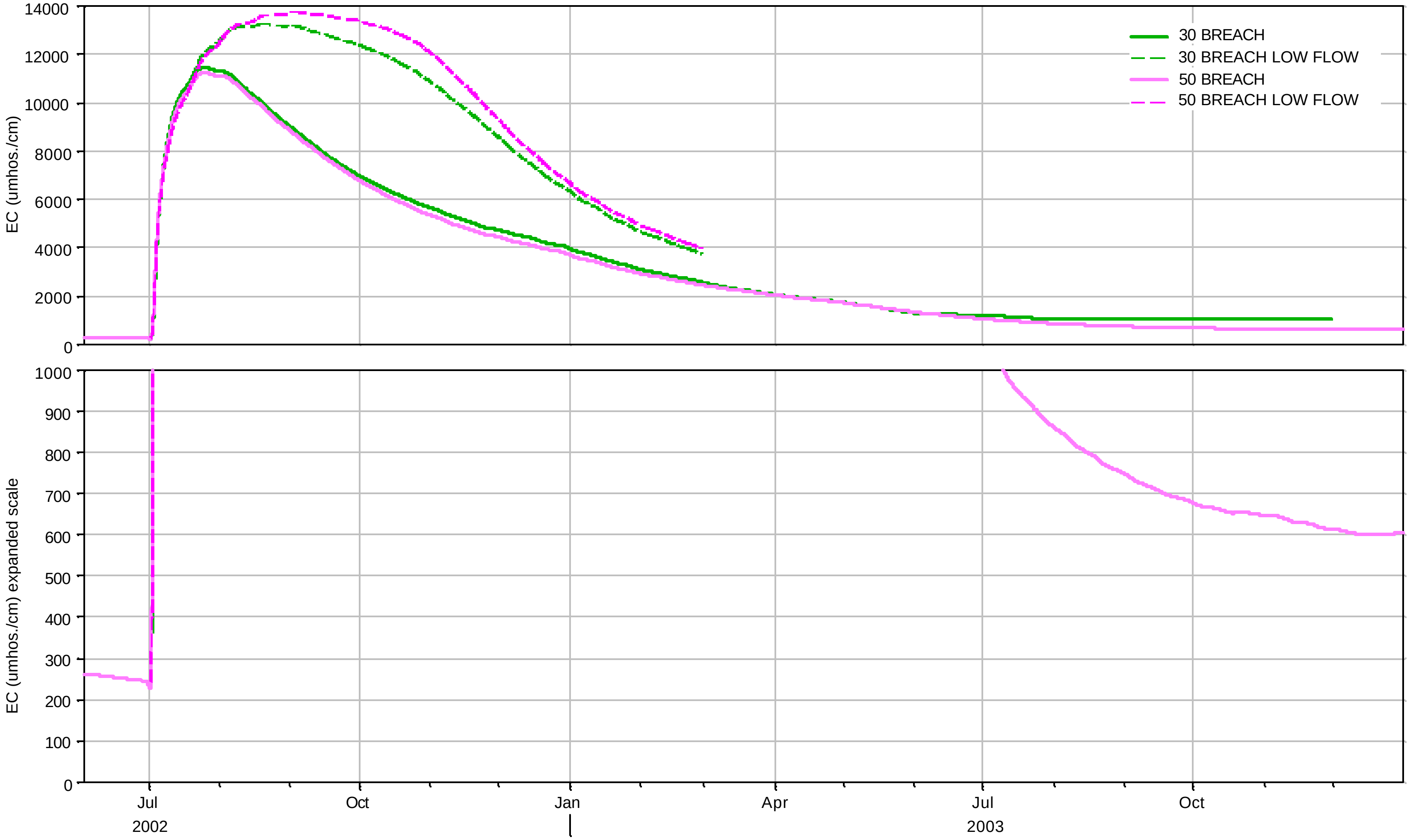

Figure 3-36 Tidally averaged EC time series in Palm Tract.

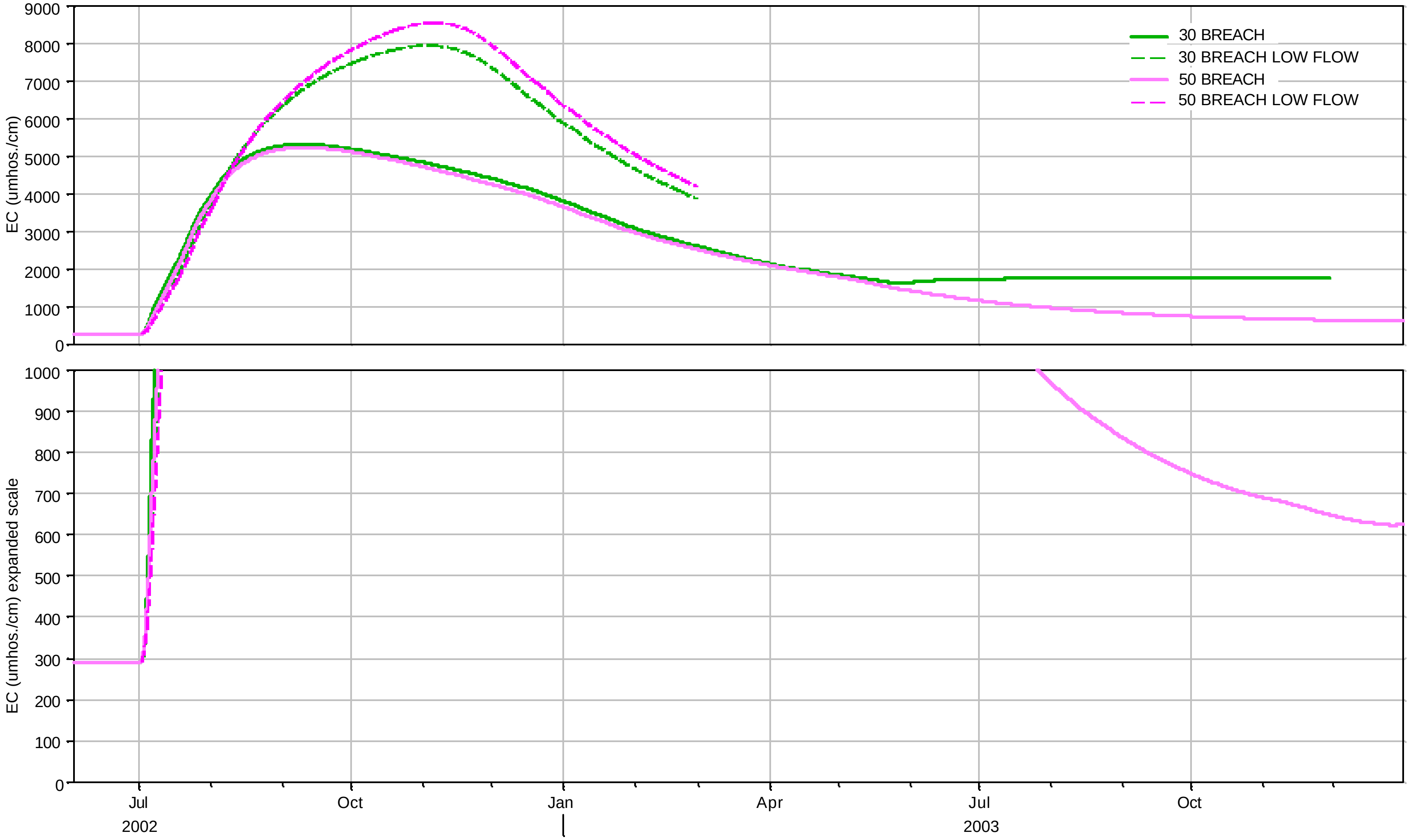

Figure 3-37 Tidally averaged EC time series in Lower Jones Tract.

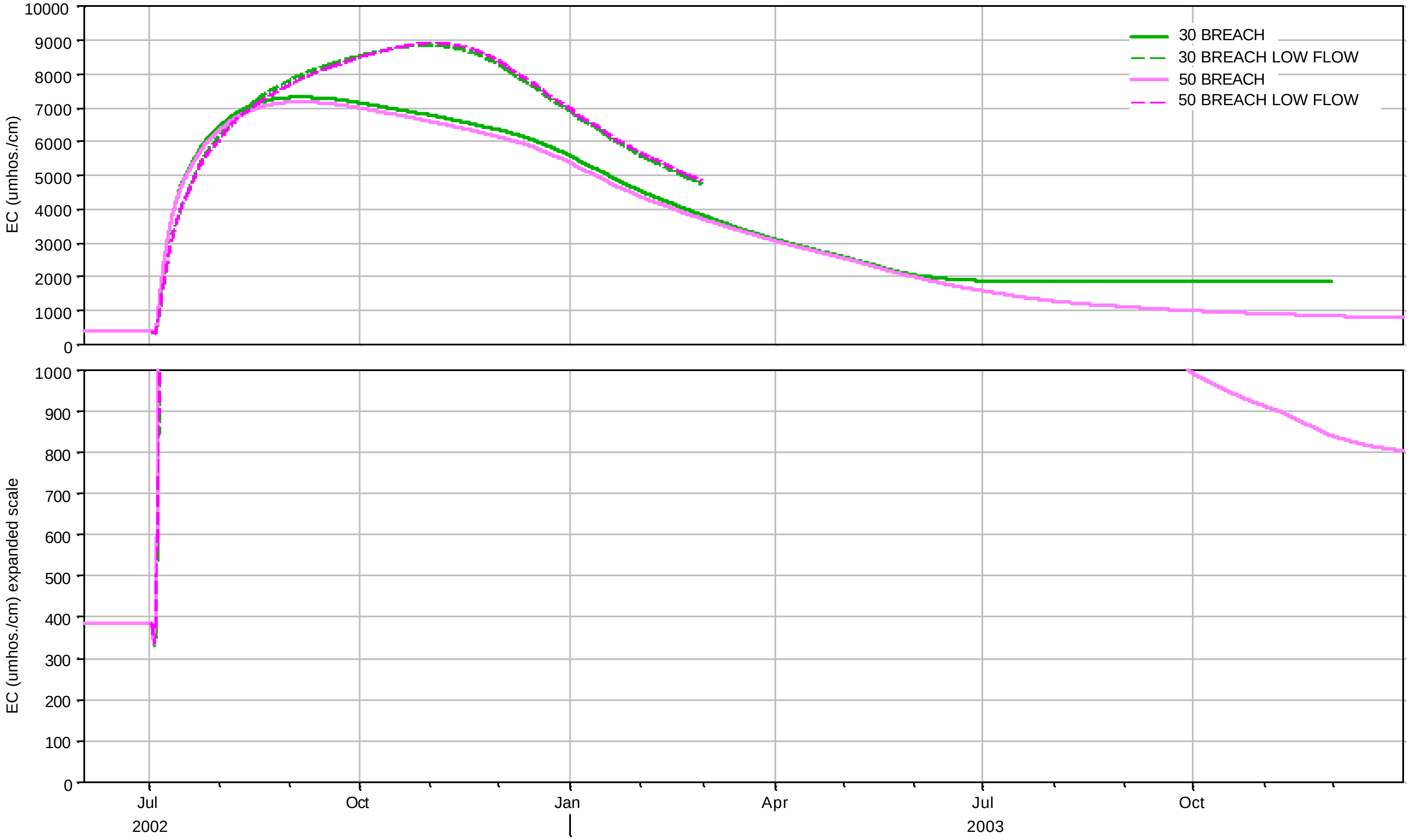

Figure 3-38 Tidally averaged EC time series in Victoria Island.

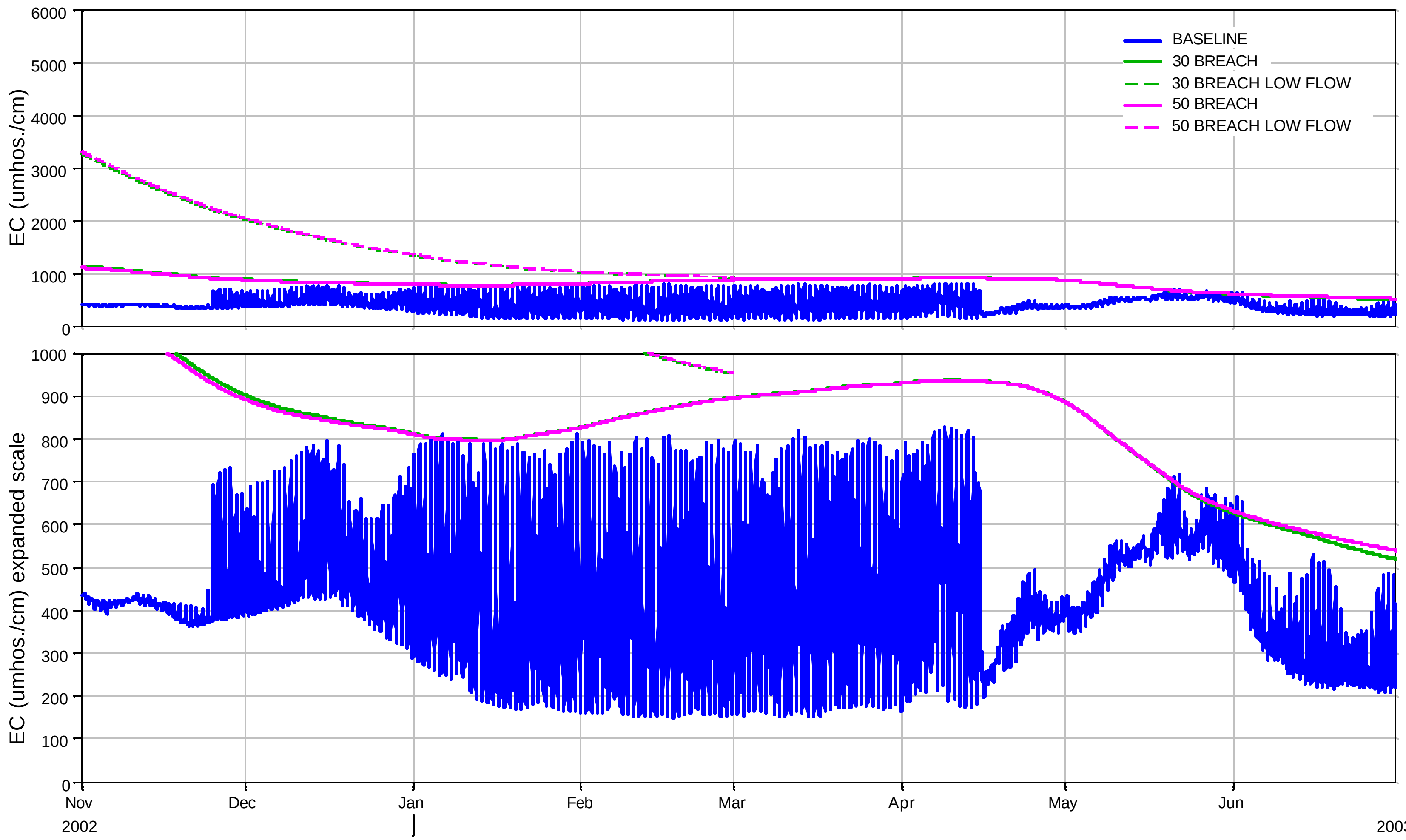

Figure 3-39 Dynamic EC time series at CVP.